XENON and DARWIN

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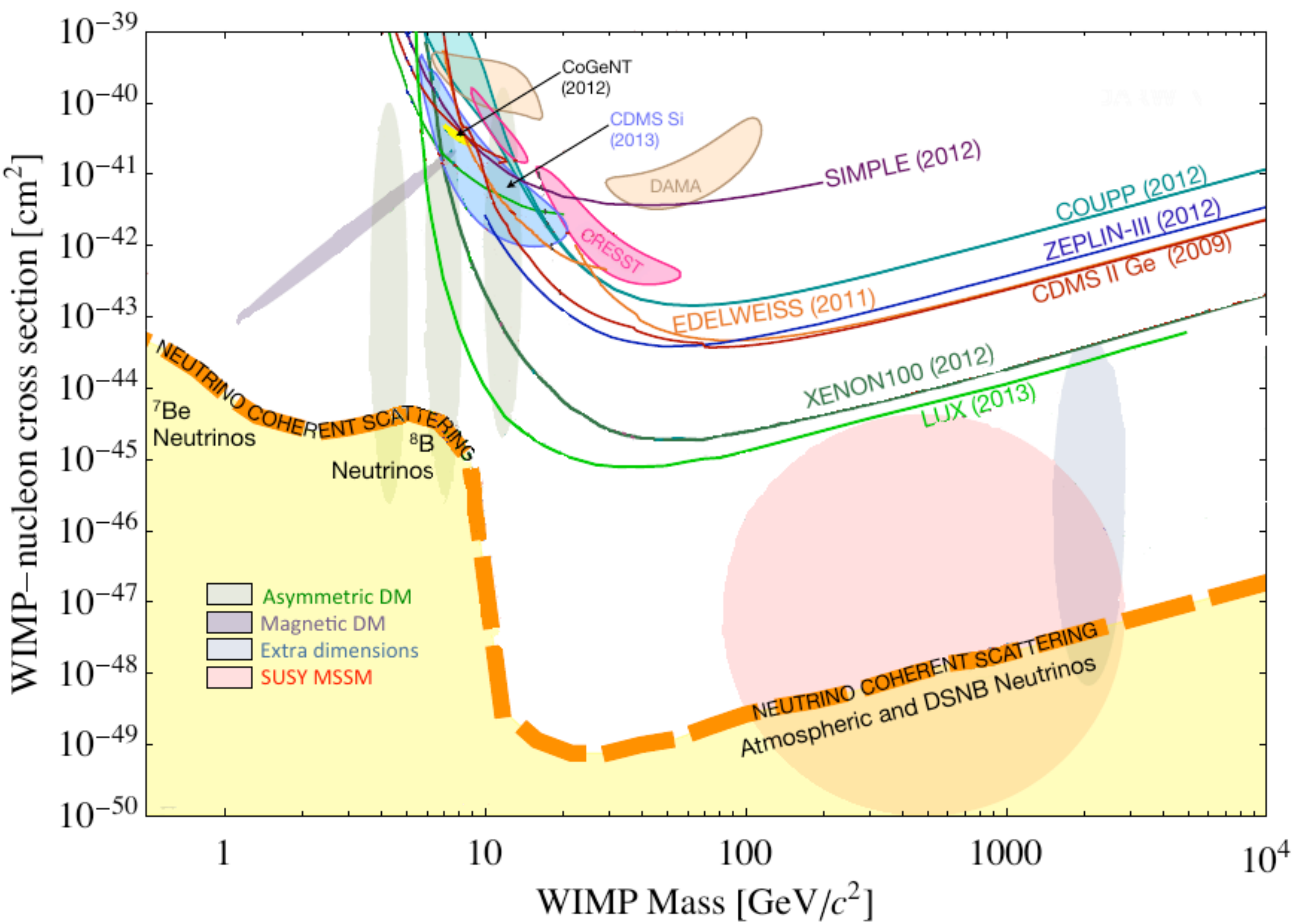
Universität Zürich[UZH]

Experimentally available parameter space for WIMPs in 2014

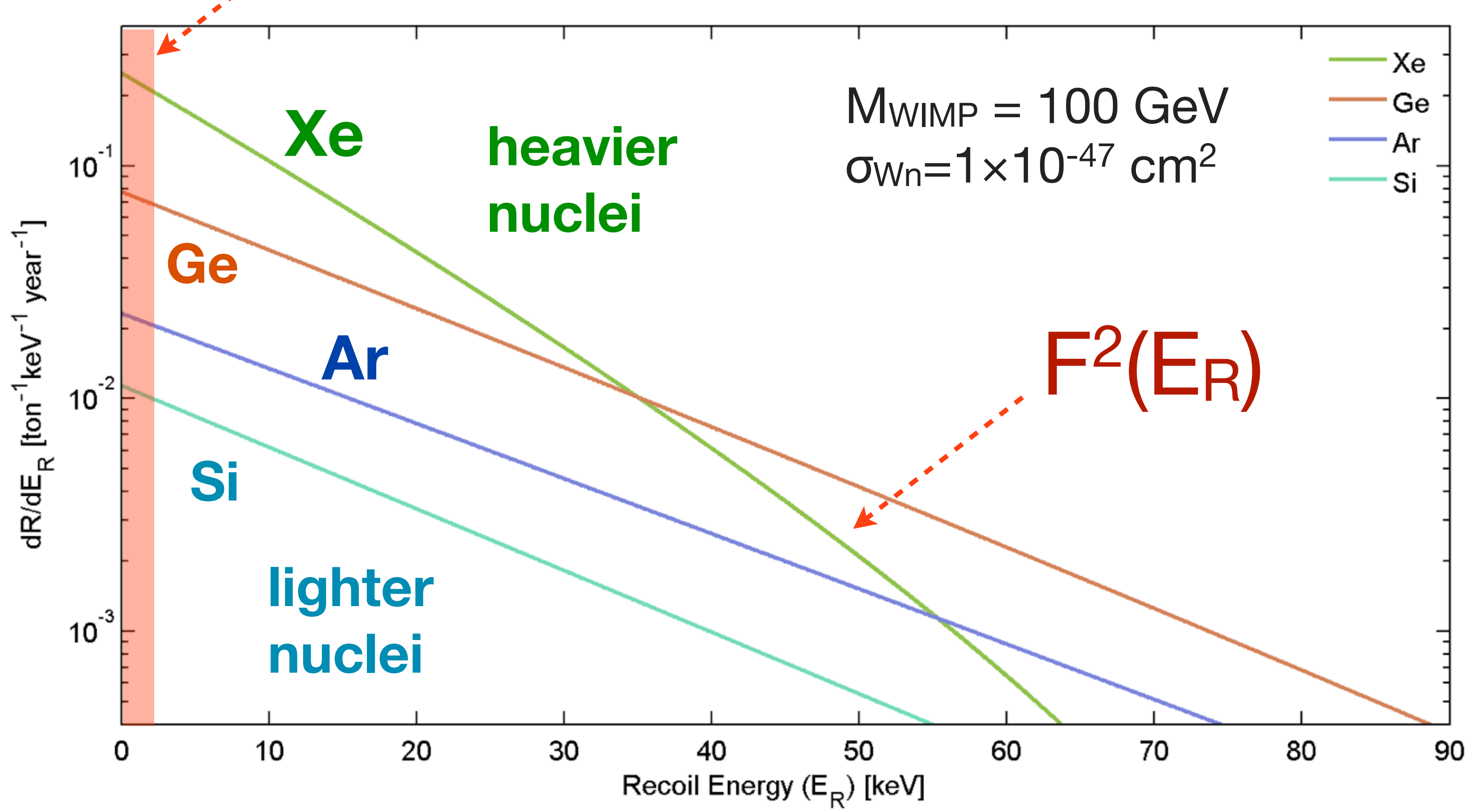


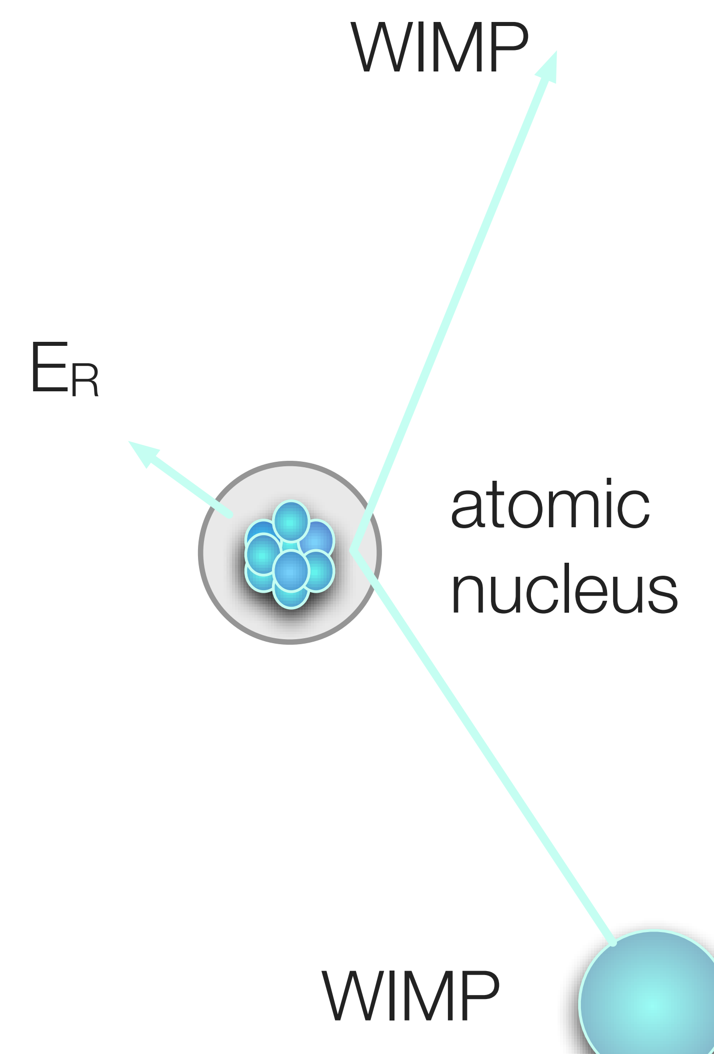
Physics aim of noble liquid dark matter experiments

- Observe WIMP dark matter via elastic scattering off xenon and argon nuclei

$$R \sim 0.13 \, \frac{\text{events}}{\text{kg year}} \left[\frac{A}{100} \times \frac{\sigma_{WN}}{10^{-38}\,\text{cm}^2} \times \frac{\langle v \rangle}{220\,\text{km}\,\text{s}^{-1}} \times \frac{\rho_0}{0.3\,\text{GeV}\text{cm}^{-3}} \right]$$

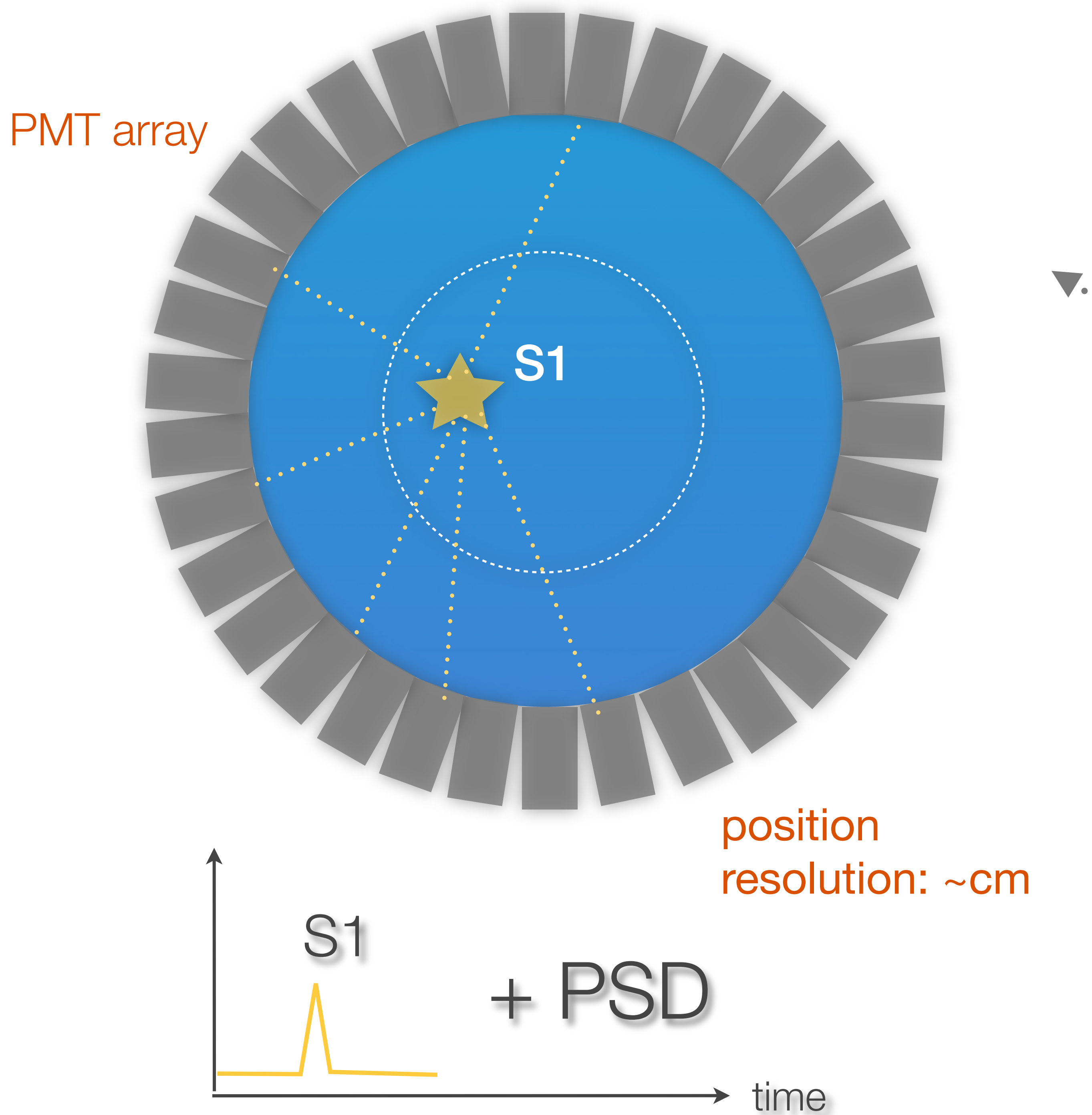
$$v_{min} = \sqrt{\frac{m_N E_{th}}{2\mu^2}}$$



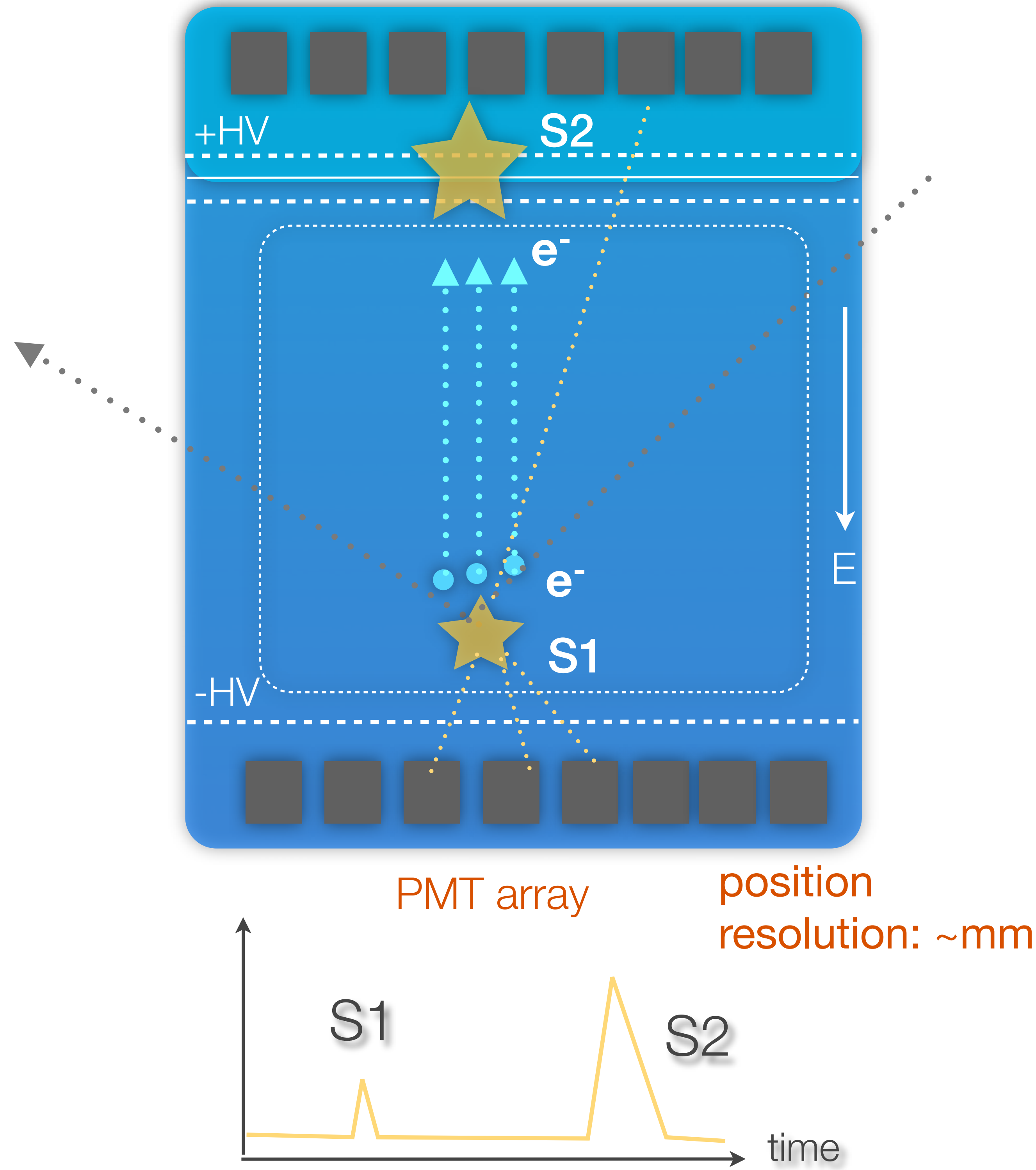


Two detector concepts

Single phase



Double phase (TPC)



The XENON100 experiment: 2008-2015

- Double phase time projection chamber with 161 kg (30-50 kg) of LXe total (fiducial), at LNGS
- 30 cm e$^-$ drift length, 30 cm diameter
- 2 arrays of 1-inch, low-background PMTs + LXe veto
- Low radioactivity - screened/selected - materials

Instrument described in:
Astroparticle Physics 35, 2012

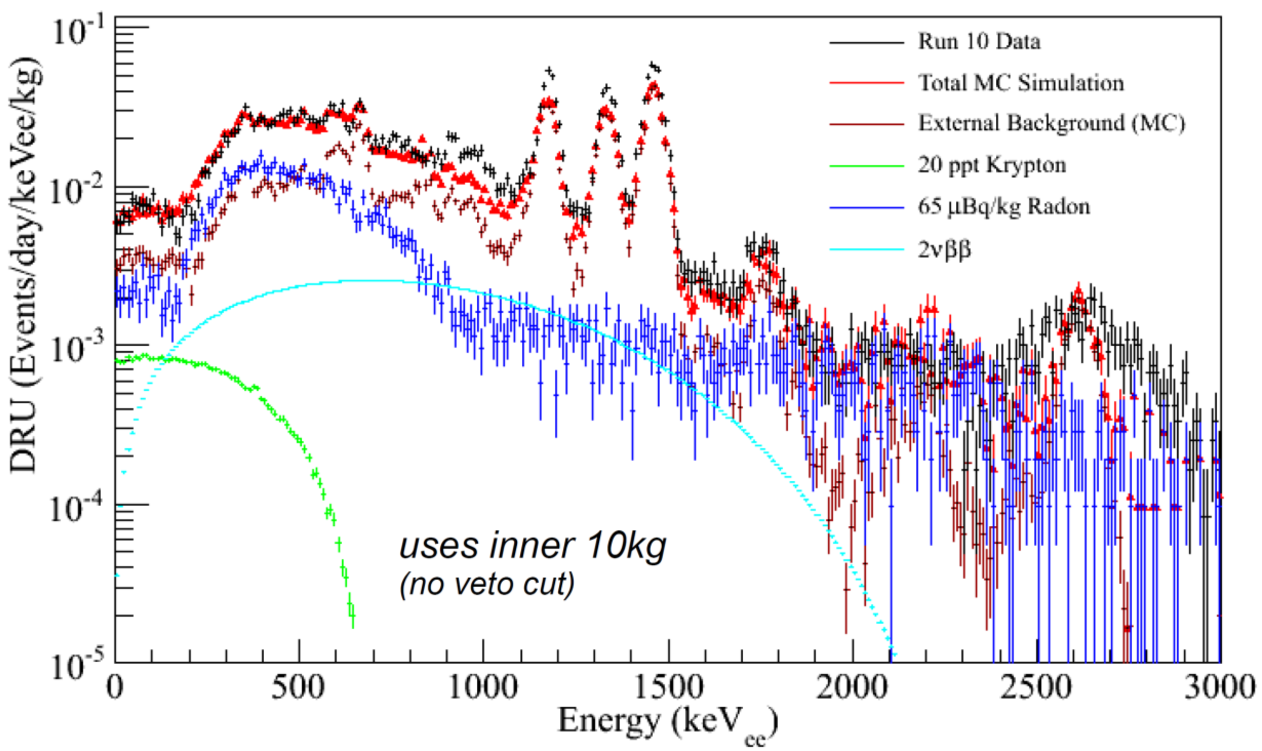
Material screening results in:
JINST 6, 2011

Detailed analysis paper:
Astroparticle Physics 54, 2014

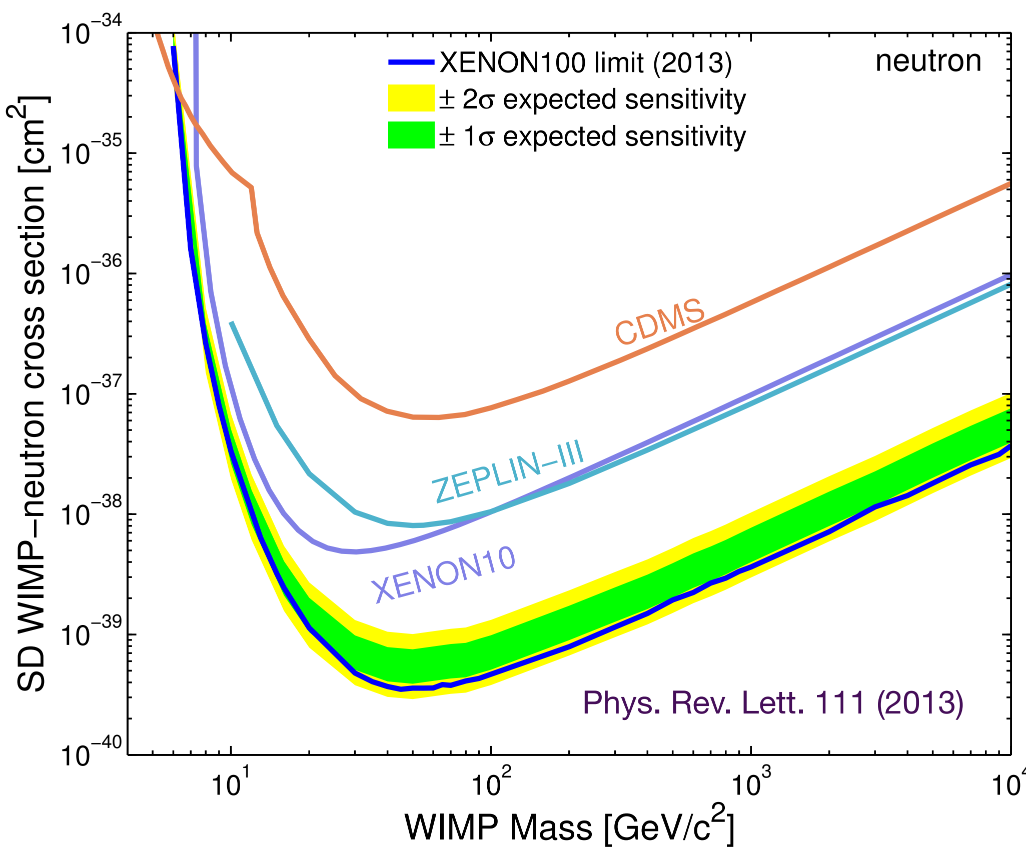
Top array: 98 PMTs

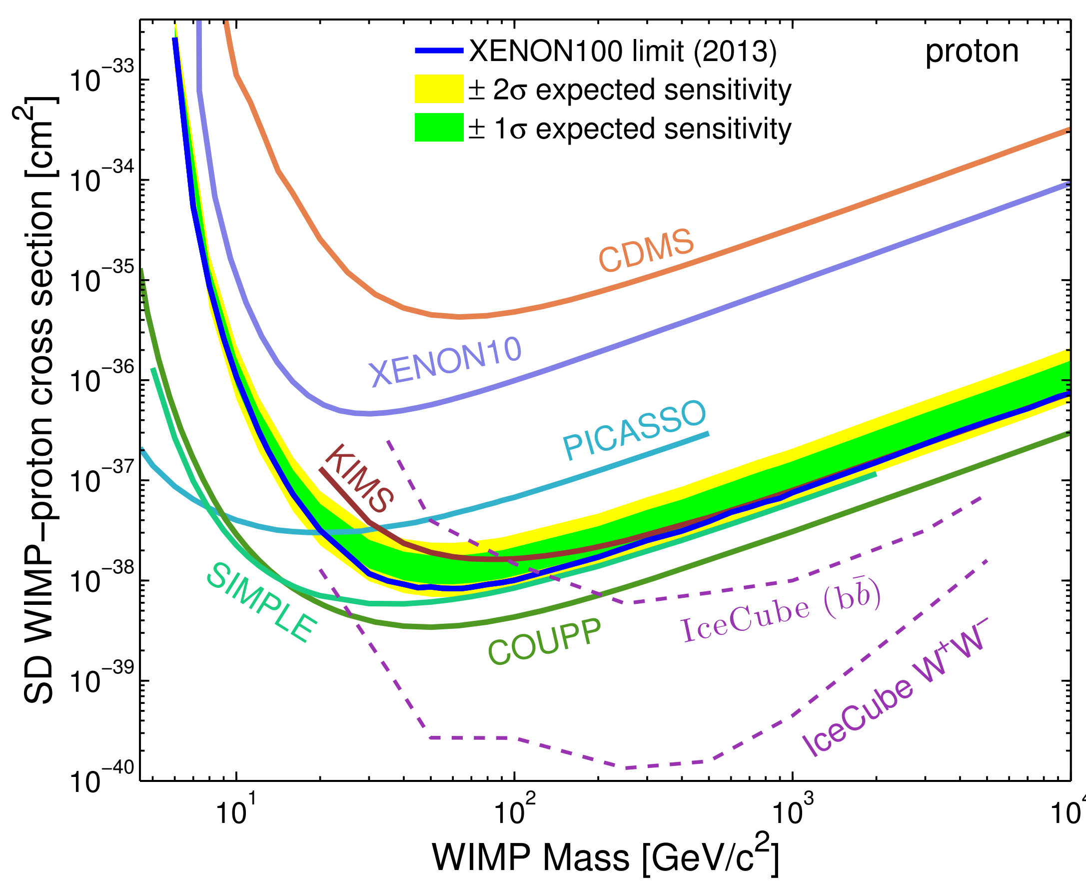
Bottom array: 80 PMTs

Results from XENON100

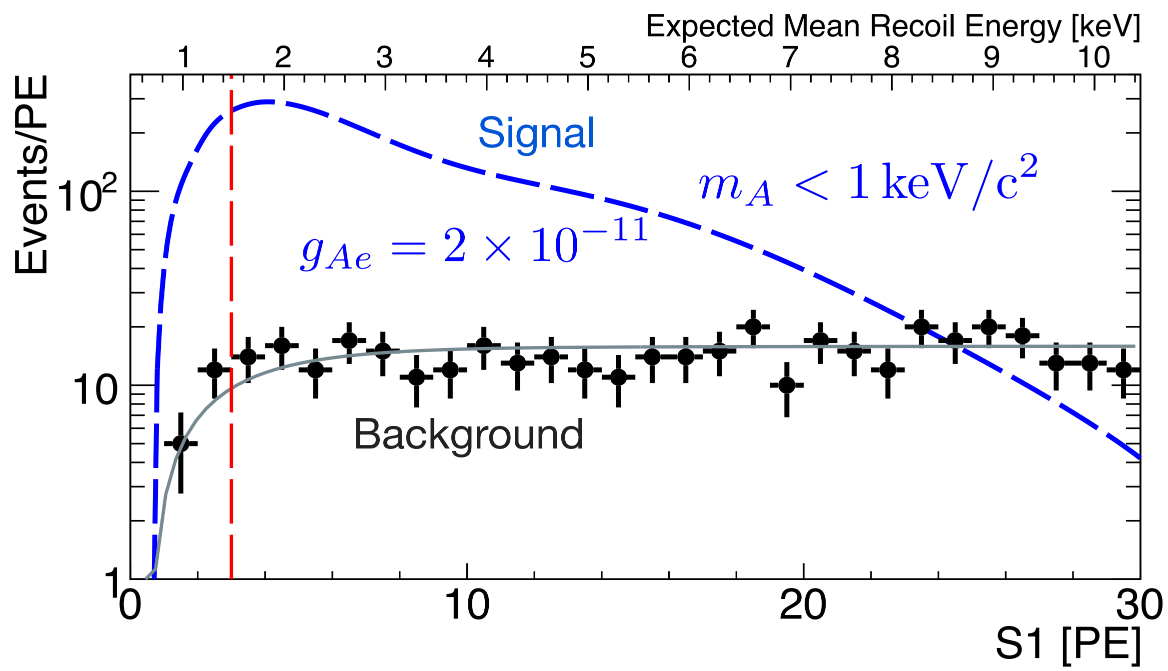


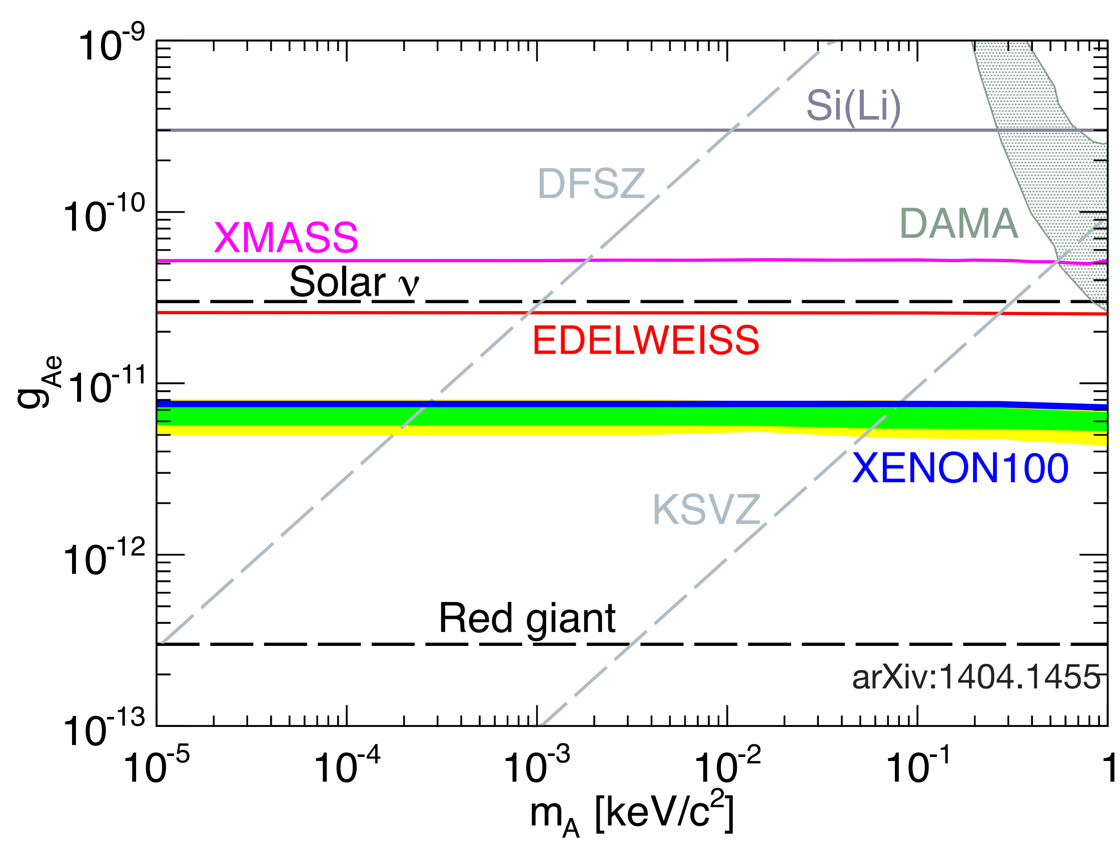
- Ultra-low background and design sensitivity achieved
- Background: ~ 5 x 10^{-3} events/(kg d keV)
- No evidence for WIMP dark matter
- Upper limits on SI, SD WIMP-nucleon cross sections (PRL 109, PRL 111)





New and upcoming results from XENON100





- Search for solar axions and galactic ALPs
- Based on the same 224.6 live days x 34 kg exposure
- Using the electronic-recoil spectrum, and measured light yield for low-energy ERs
- Next: annual modulation, low-mass WIMPs, inelastic scattering on ^{129}Xe (and additional 150 days run close to unblinding)

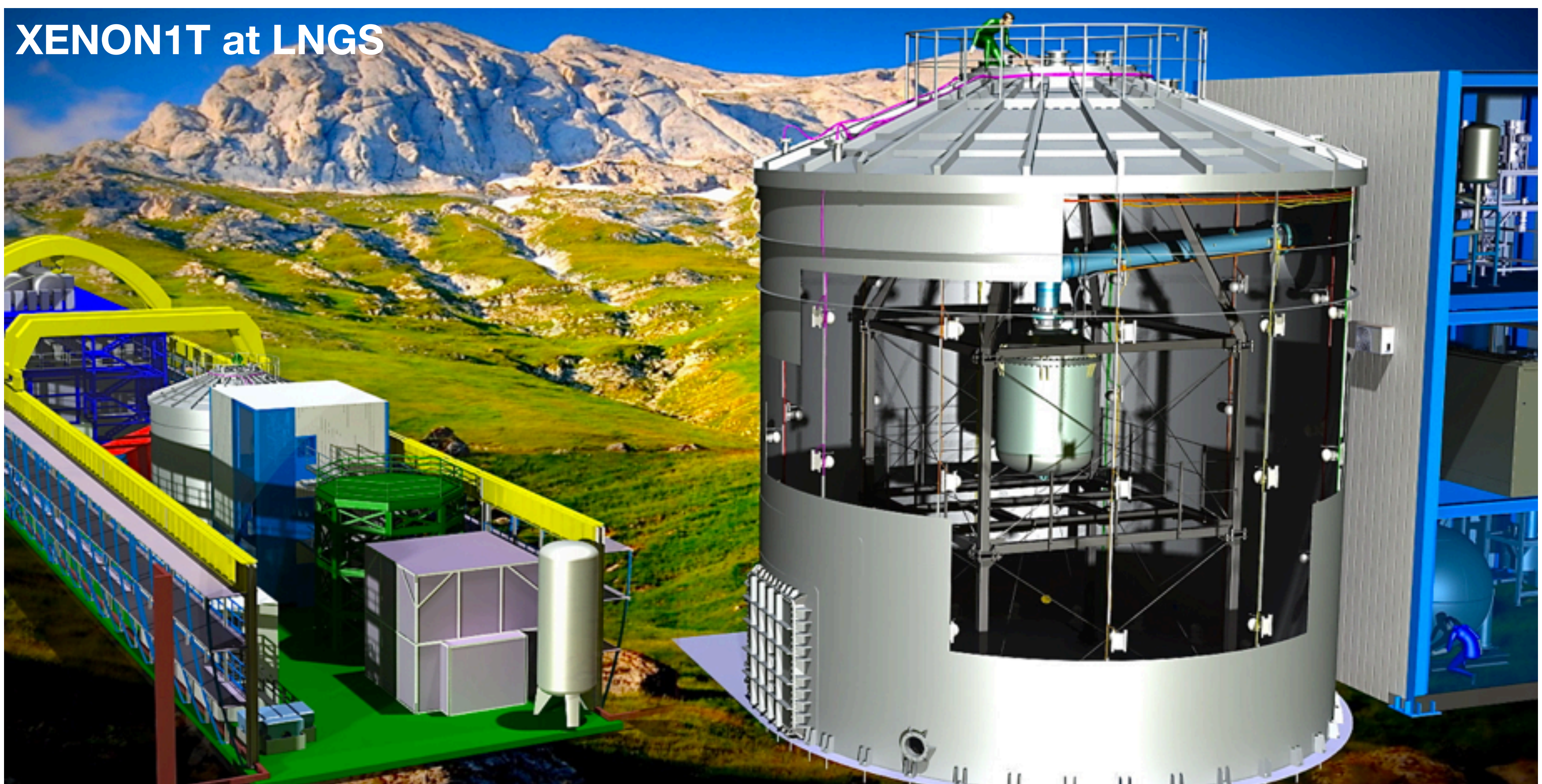
Look for solar axions via their couplings to electrons, g_{Ae}, through the axio-electric effect

$$\sigma_{Ae} = \sigma_{pe}(E_A)\frac{{g_{Ae}}^2}{\beta_A}\frac{3{E_A}^2}{16\pi\,\alpha_{em}\,{m_e}^2}\left(1 - \frac{\beta_A^{2/3}}{3}\right)$$

$$\phi_A \propto g_{Ae}^2 \qquad \Rightarrow R_{exp} \propto g_{Ae}^4$$

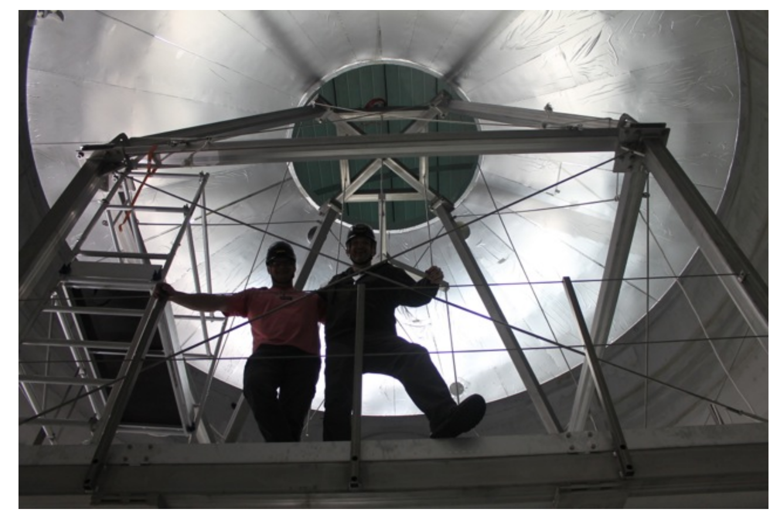
The XENON1T experiment

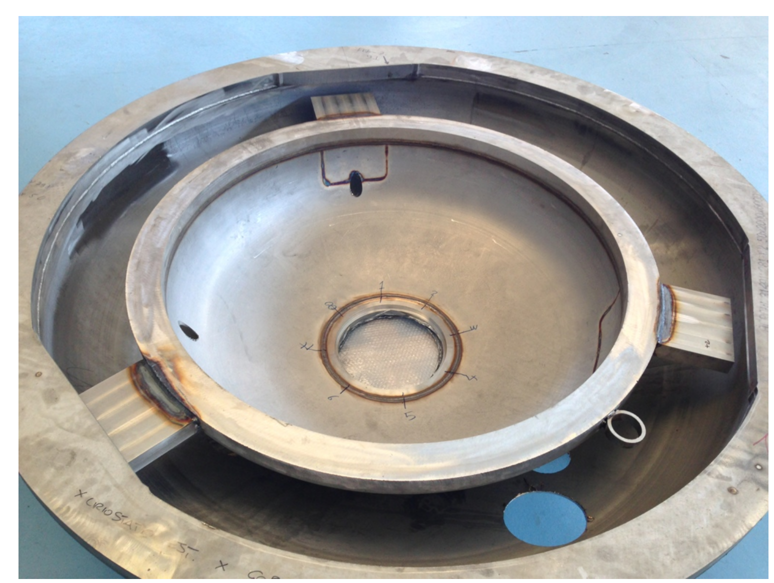
- Under construction at LNGS since autumn 2013; commissioning planned for 2015
- Total (active) LXe mass: 3.3 t (2 t), 1 m electron drift, 248 3-inch PMTs in two arrays
- Background goal: 100 x lower than XENON100 ~ 5×10^{-2} events/(t d keV)



XENON1T: status of construction work

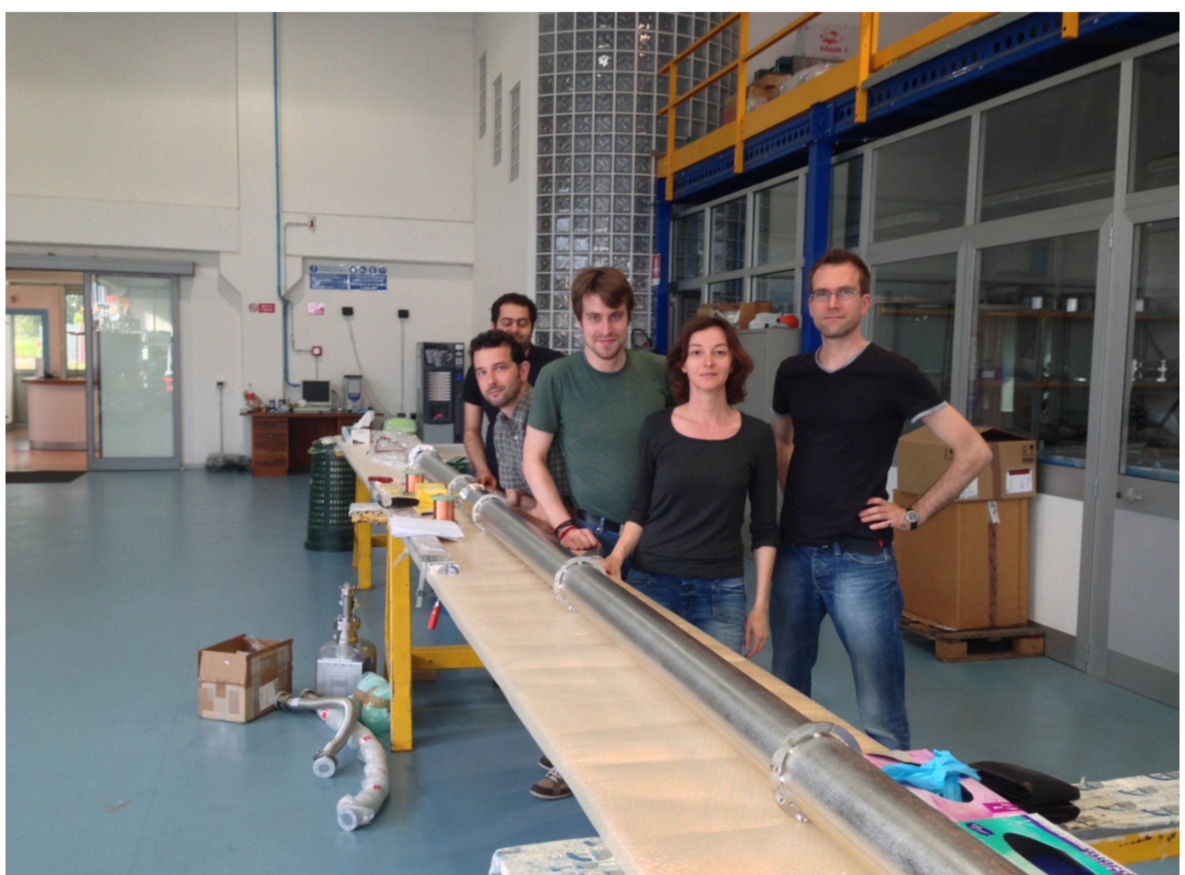
- Water tank, PMT holders, service building, electrical plant completed
- Support structure for the cryostat installed in the water tank
- Integration of several subsystems (cryostat, cryogenics, storage, purification, cables, pipes) already started, or to start this summer





XENON1T: status of construction work

- Last week: ~9 km of cables (signal + HV, XENON1T+nT) installed in the 8 m long "umbilical pipe" connecting the inner detector, through the water shield, to the outside
- This week: pipe baked and pumped (to ~3e-5 mbar); now Rn emanation measurement in progress

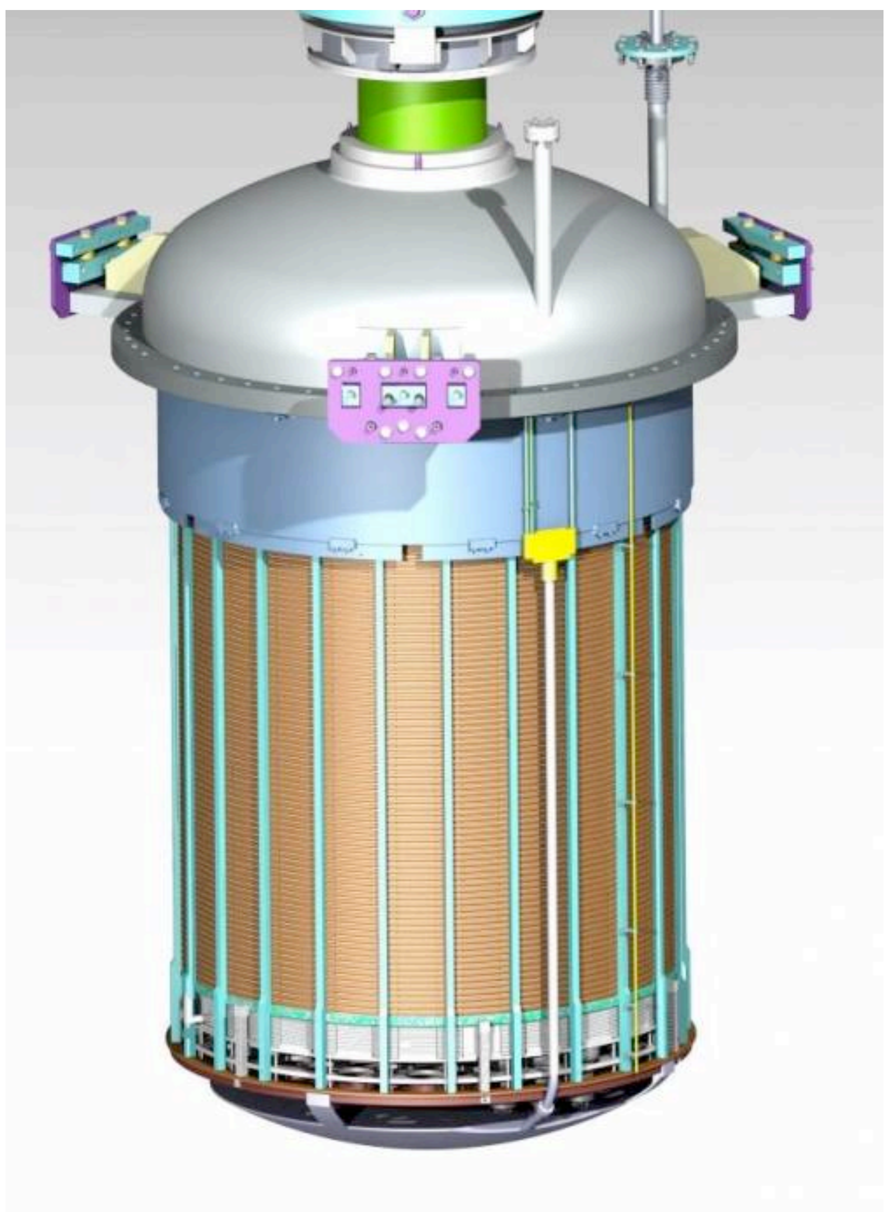


XENON1T outer cryostat

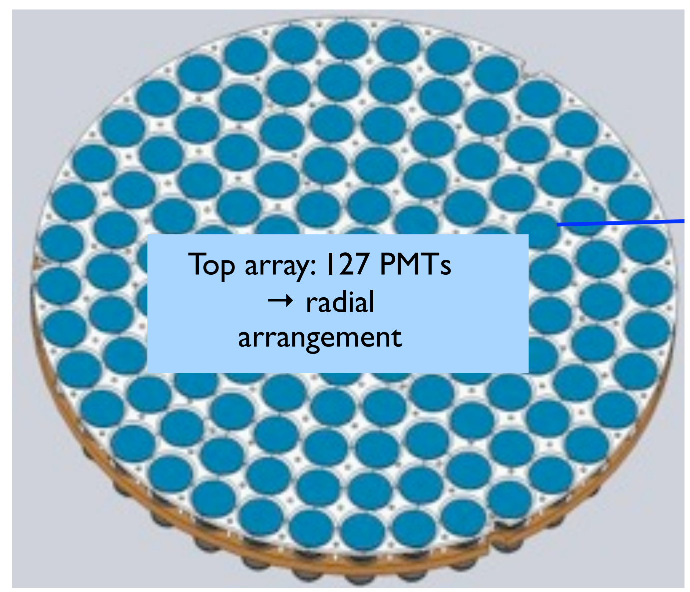
The XENON1T inner detector

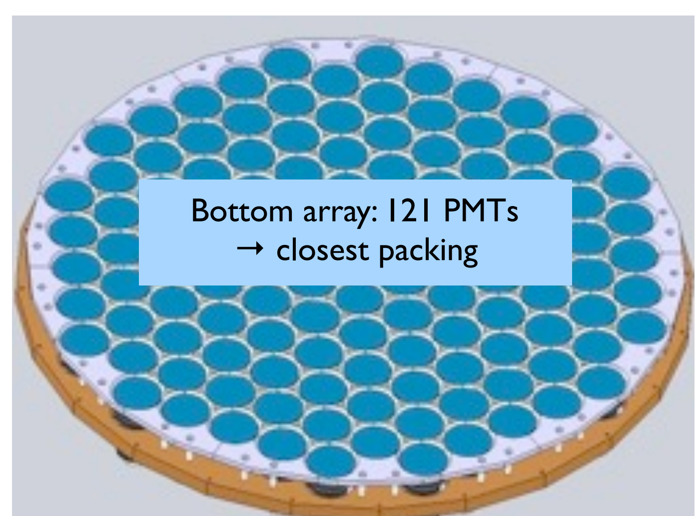
- PMTs are screened with HPGe, then tested in cold gas and - a subsample - in LXe
- TPC design is finalized, currently under prototyping, materials being screened

The TPC

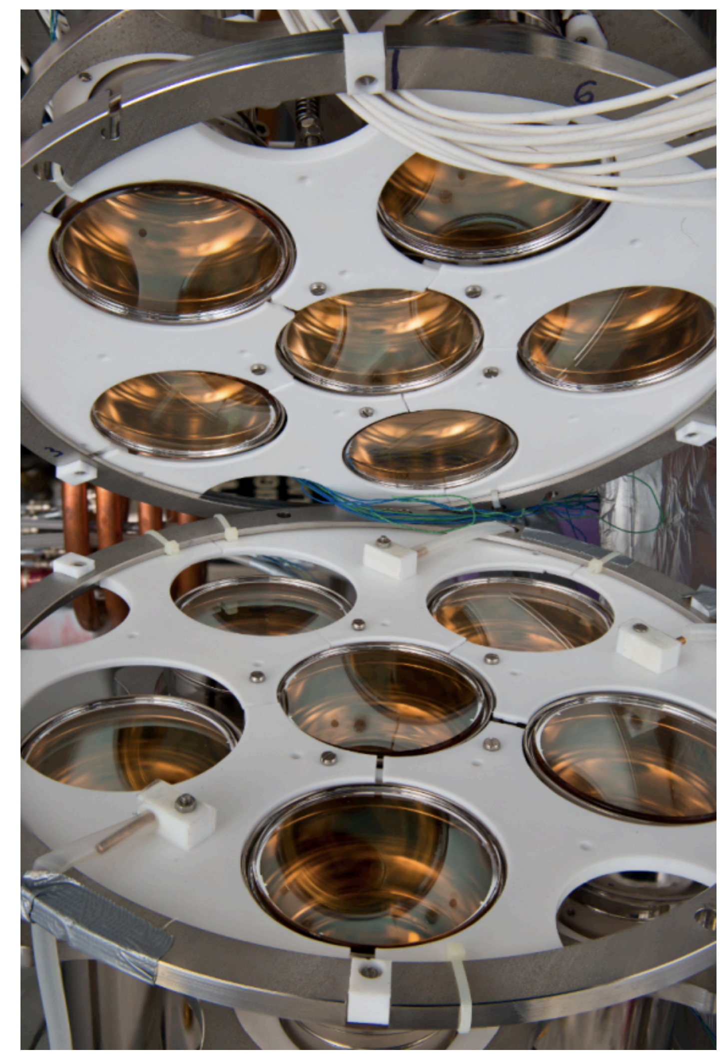


127 3” sensors top



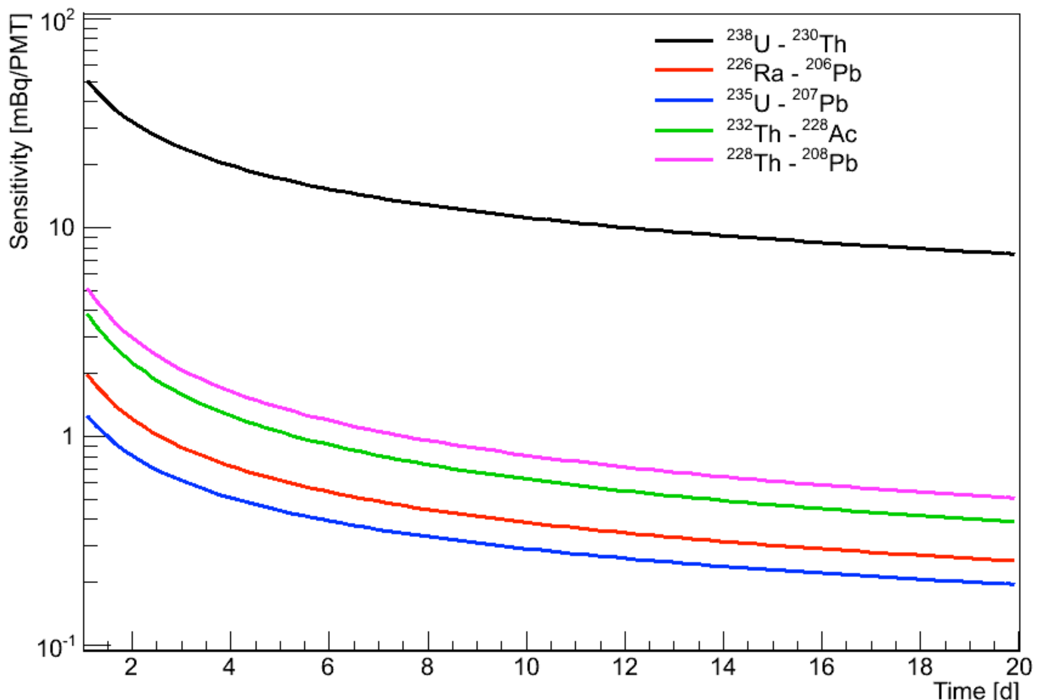


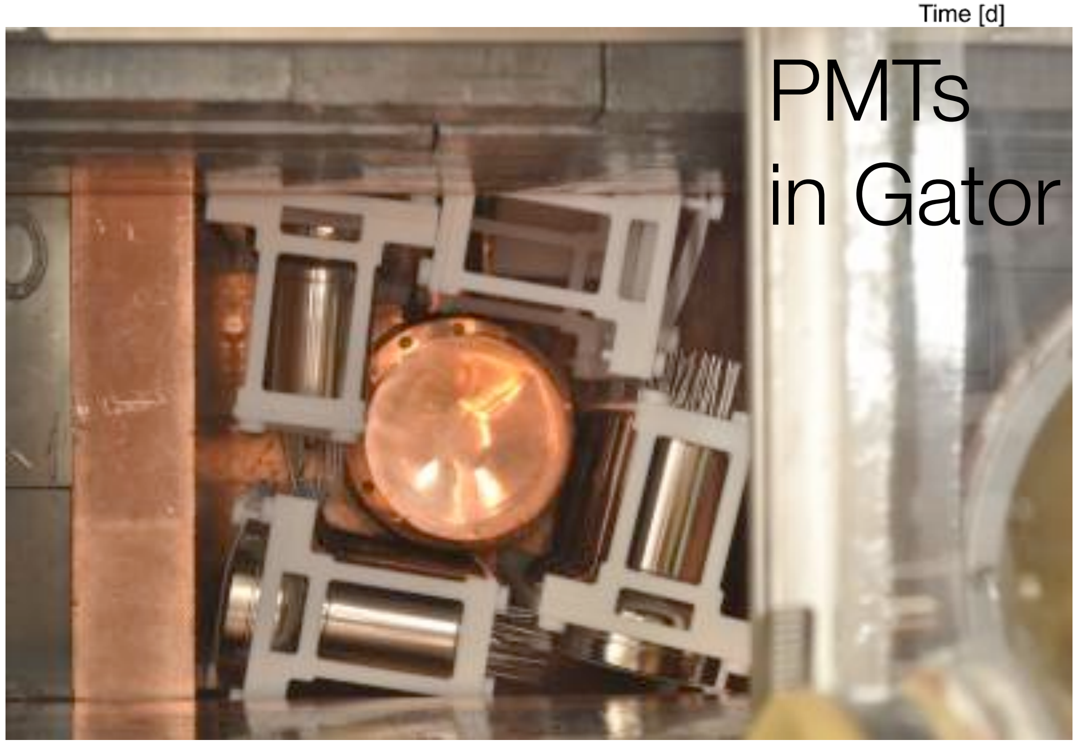
121 3” sensors bottom



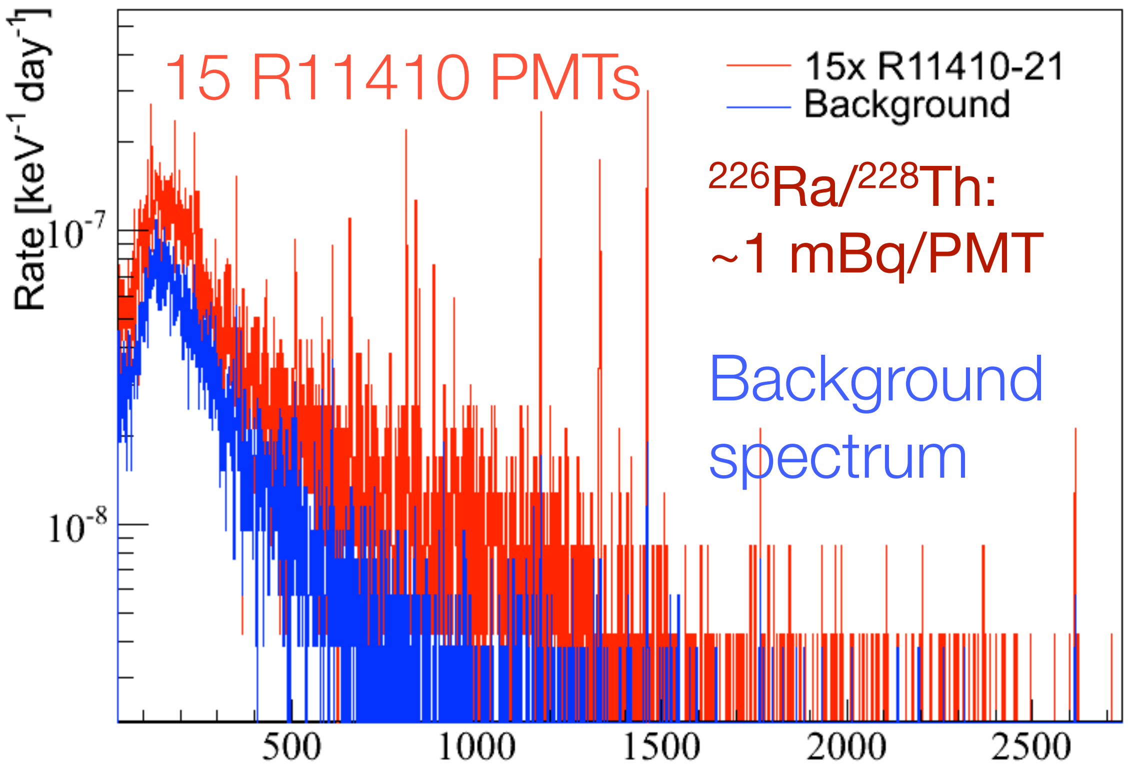
The XENON1T photosensors

R11410-21 3-inch PMTs; average QE at 175 nm: 36%, average gain: 3 x 10^6 at 1500 V



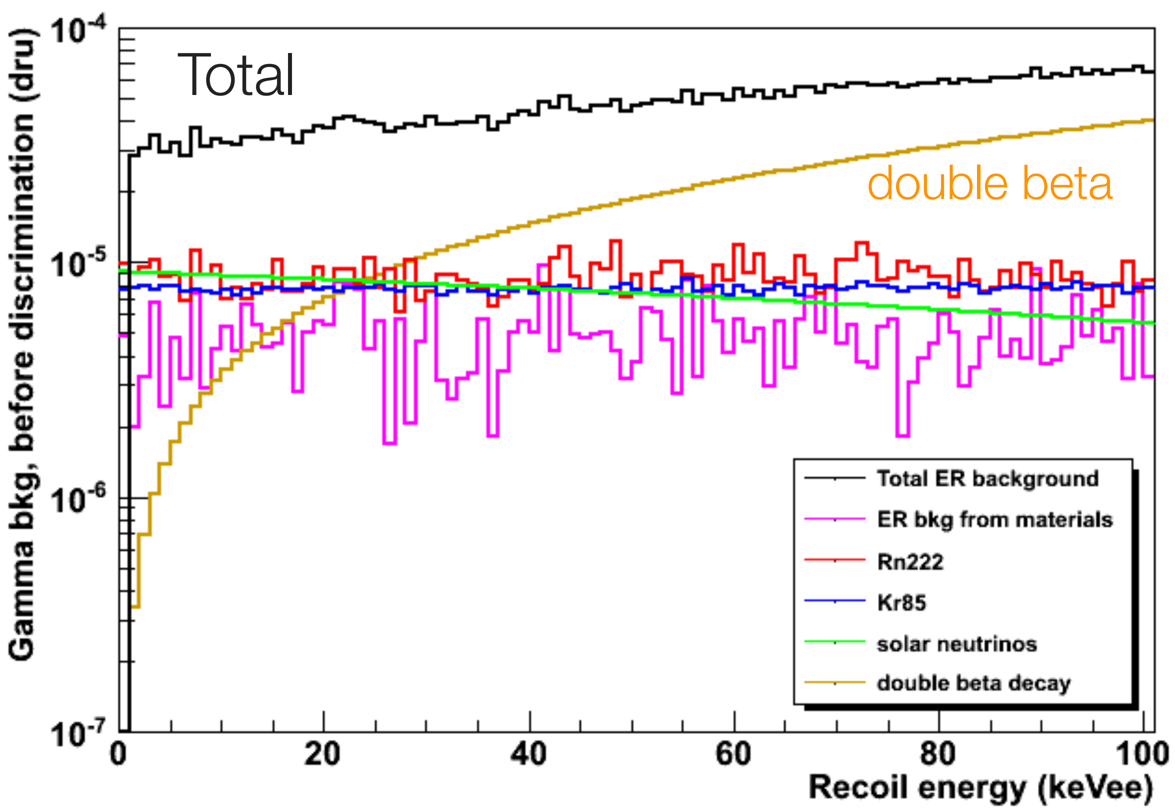


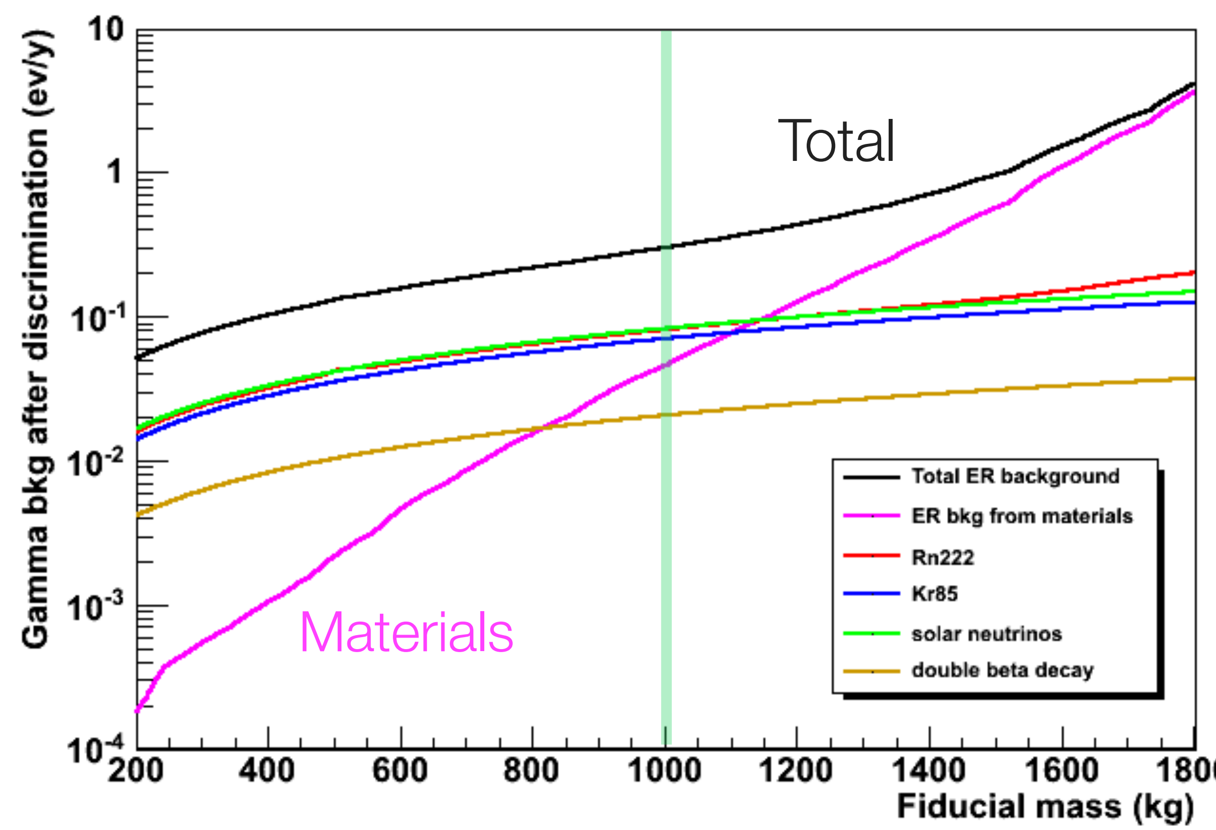
Gator: LB et al, JINST 6 P08010, 2011



XENON1T background predictions

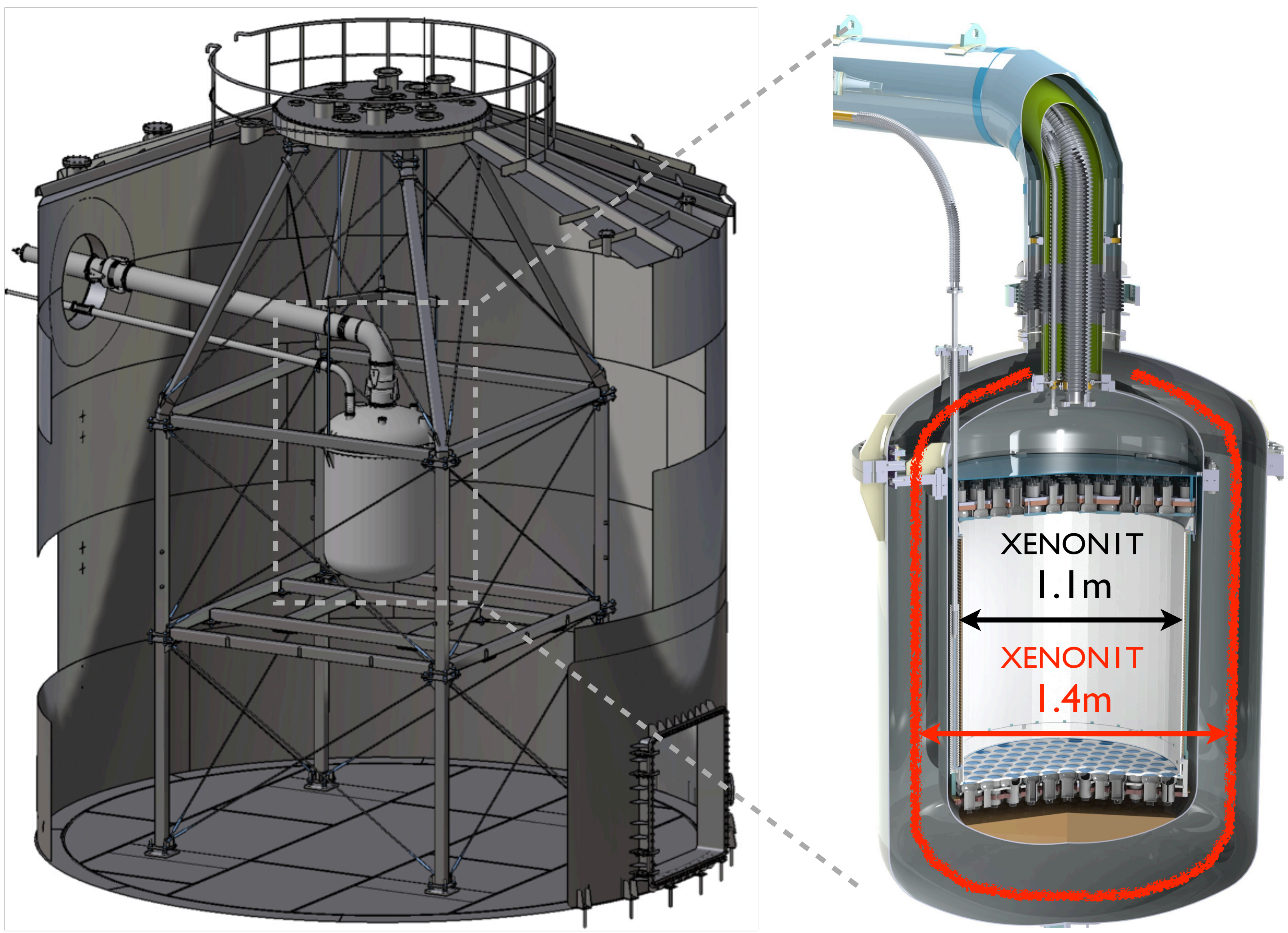
- Materials background: based on screening results for most detector components
- ^{85}Kr: 0.2 ppt of ^{nat}Kr with $2x10^{-11}$ ^{85}Kr; Rn: 1 µBq/kg; double beta: $2.11x10^{21}$ years, ^{136}Xe
- ER vs NR discrimination level: 99.75%; 50% acceptance for NRs
  - ➡ Total ERs: 0.3 events/year in 1 ton fiducial volume, [2-12] keV_{ee}
  - ➡ Total NRs: 0.2 events/year in 1 ton, [5-50] keV_{nr} (muon-induced n-BG < 0.01 ev/year)





XENONnT: 2018-2020

- Double the amount of LXe (~7 tons), double the number of PMTs
- XENON1T is designed such that many sub-systems will be reused for the upgrade:



- Water tank + muon veto
- Outer cryostat and support structure
- Cryogenics and purification system
- LXe storage system
- Cables installed for XENONnT as well
- More LXe, PMTs, electronics will be needed

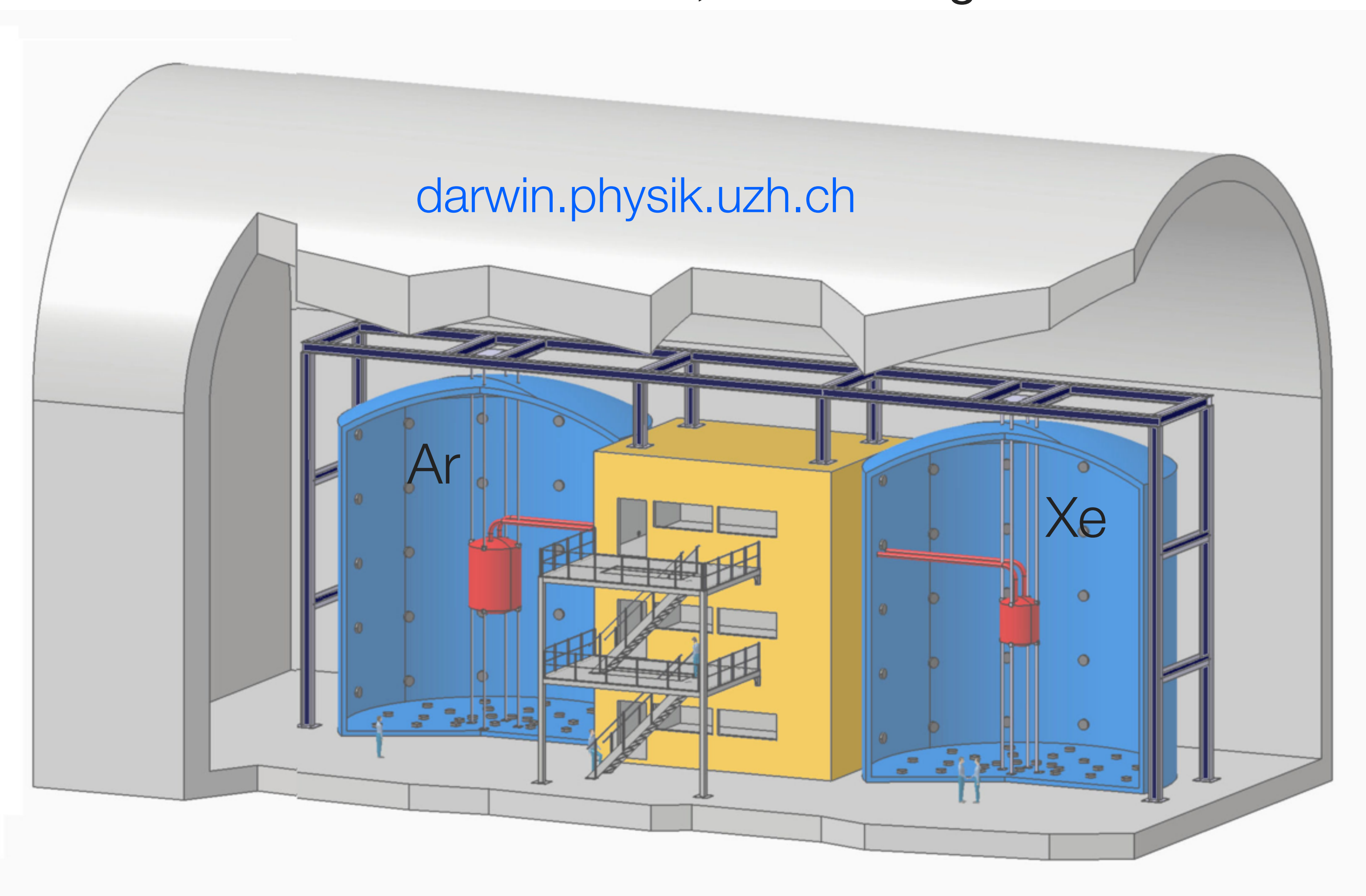
The XENON collaboration

Columbia Rice UCLA Zürich Coimbra LNGS INFN SJTU Purdue

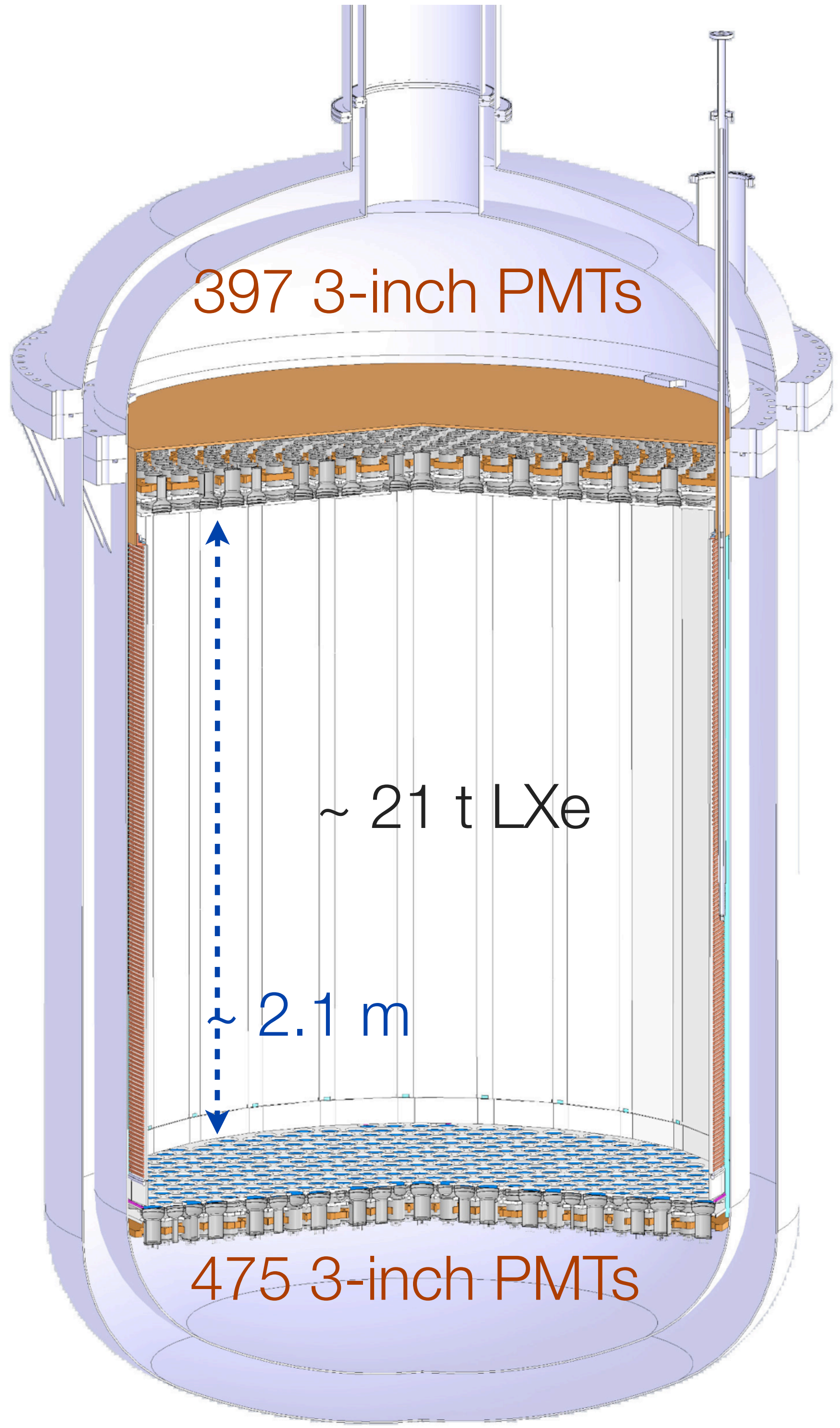
Bologna Subatech Münster Heidelberg Nikhef Weizmann Mainz Bern

DARWIN: the ultimate dark matter detector

- ASPERA design study; on the European and Swiss astroparticle physics roadmaps
- Currently in the R&D and design phase
- 20 t LXe, 30 t LAr TPCs
- Start construction in 2020, data taking in 2022

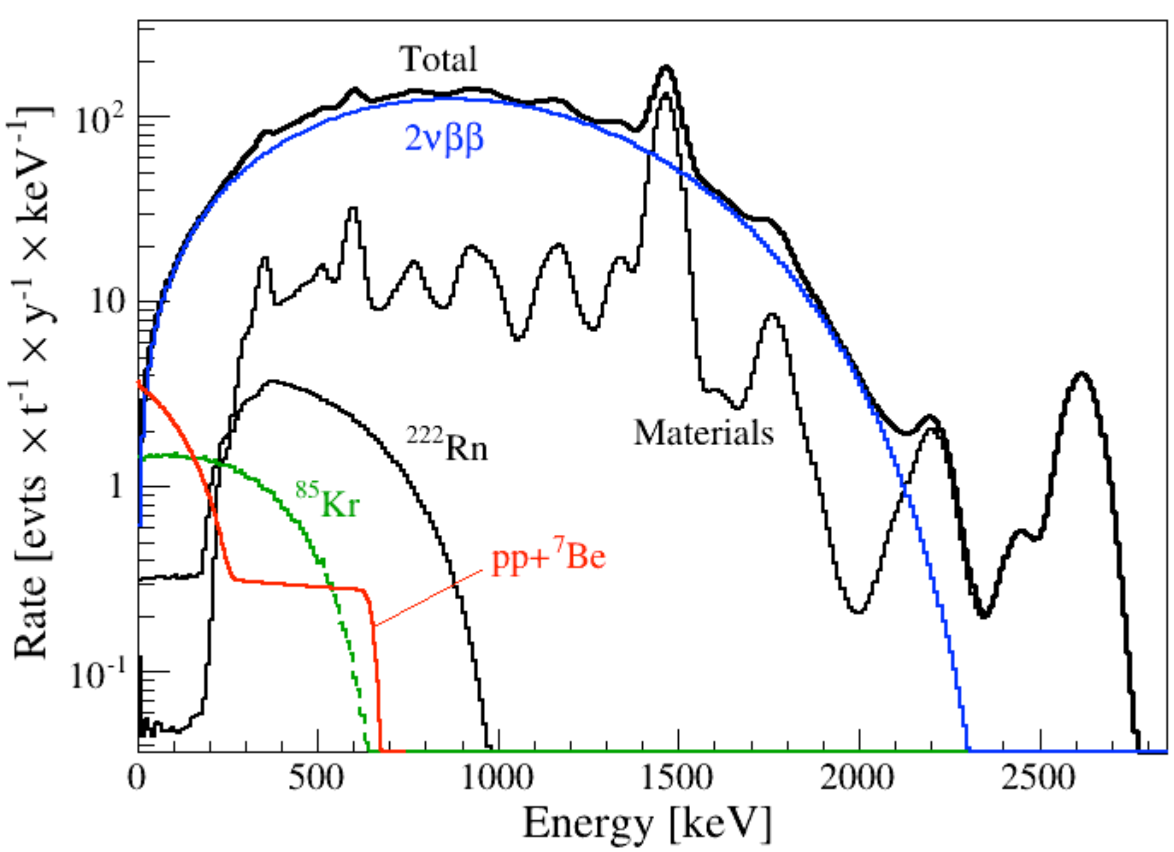


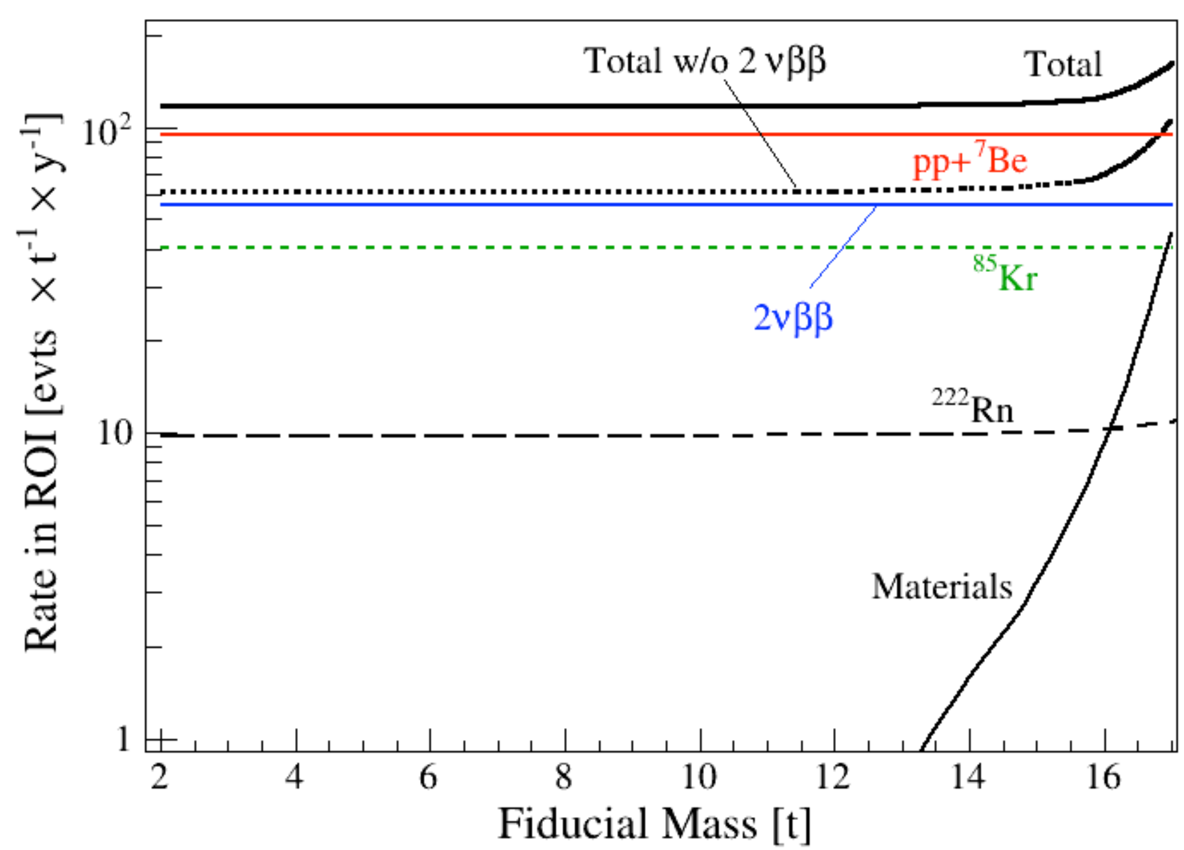
Example for a LXe TPC



Expected backgrounds in DARWIN

- From detailed MC simulations, employing 20 t LXe geometry and Geant4
- Electronic recoils: dominated by solar neutrinos and 2-neutrino double beta decays of ^{136}Xe (assumptions: 0.1 ppt of ^{nat}Kr, 0.1 µBq/kg ^{222}Rn)
- Nuclear recoils (as expected from WIMPs and fast neutrons): < 0.03 events/t/y

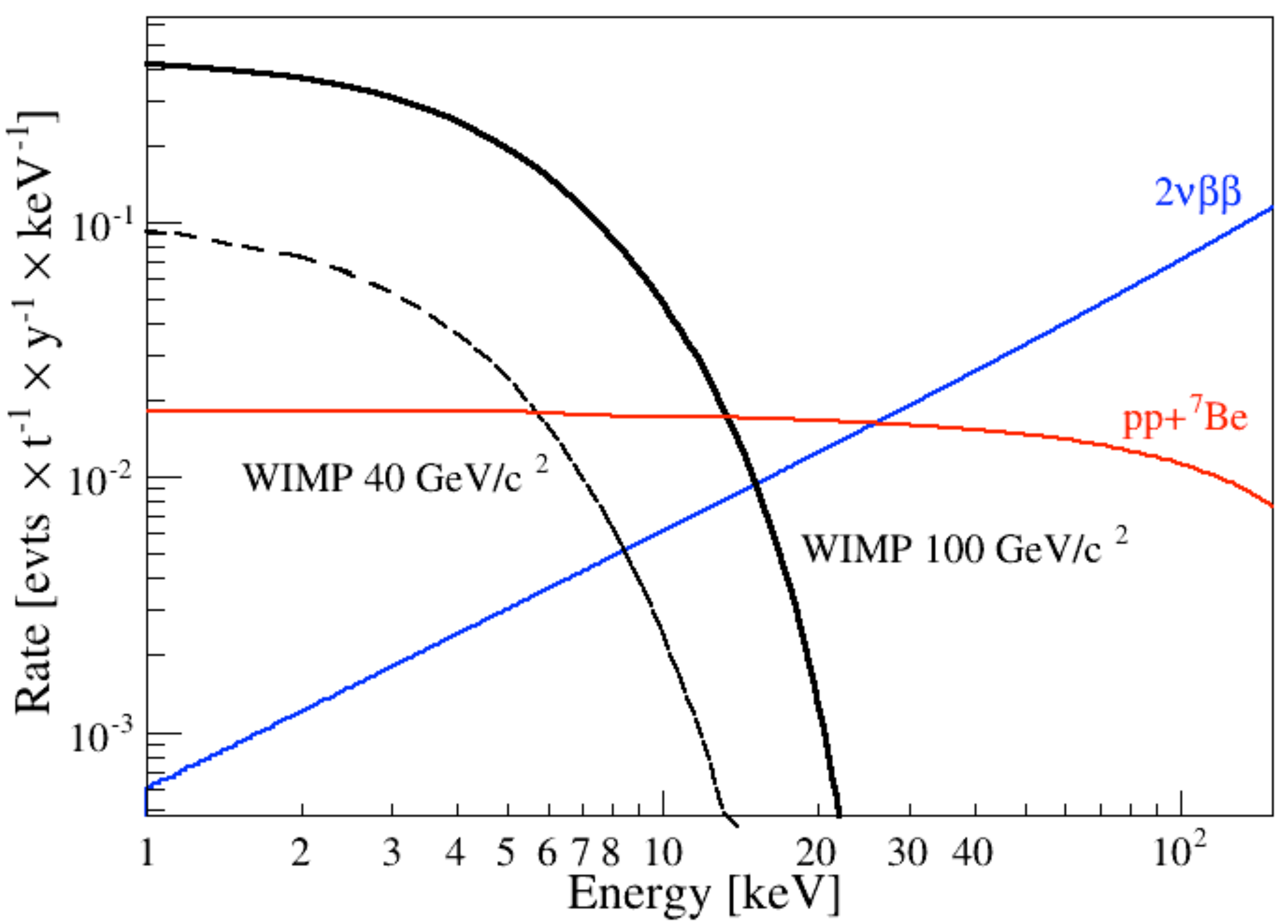




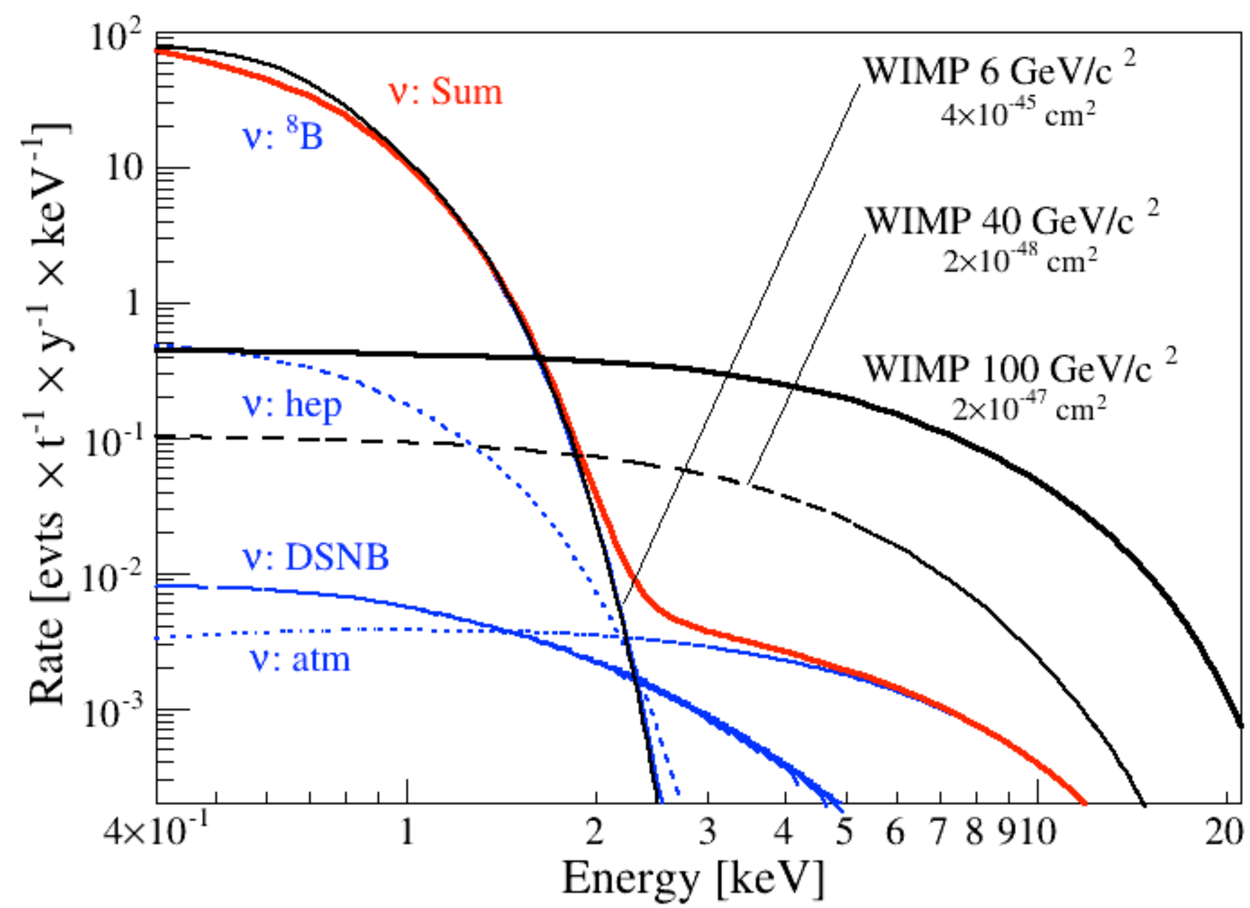
LB et al., JCAP01 (2014) 044

Backgrounds and WIMPs

- A WIMP with a mass of 40 GeV (100 GeV) and sigma=2x10^{-48} cm^2 (2x10^{-47} cm^2) is well above the solar neutrino background
- A WIMP with a mass of 6 GeV and sigma=4x10^{-45} cm^2 has a similar rate as solar ^{8}B neutrinos interacting via coherent neutrino-nucleus scatters



$$\nu + e^- \rightarrow \nu + e^-$$



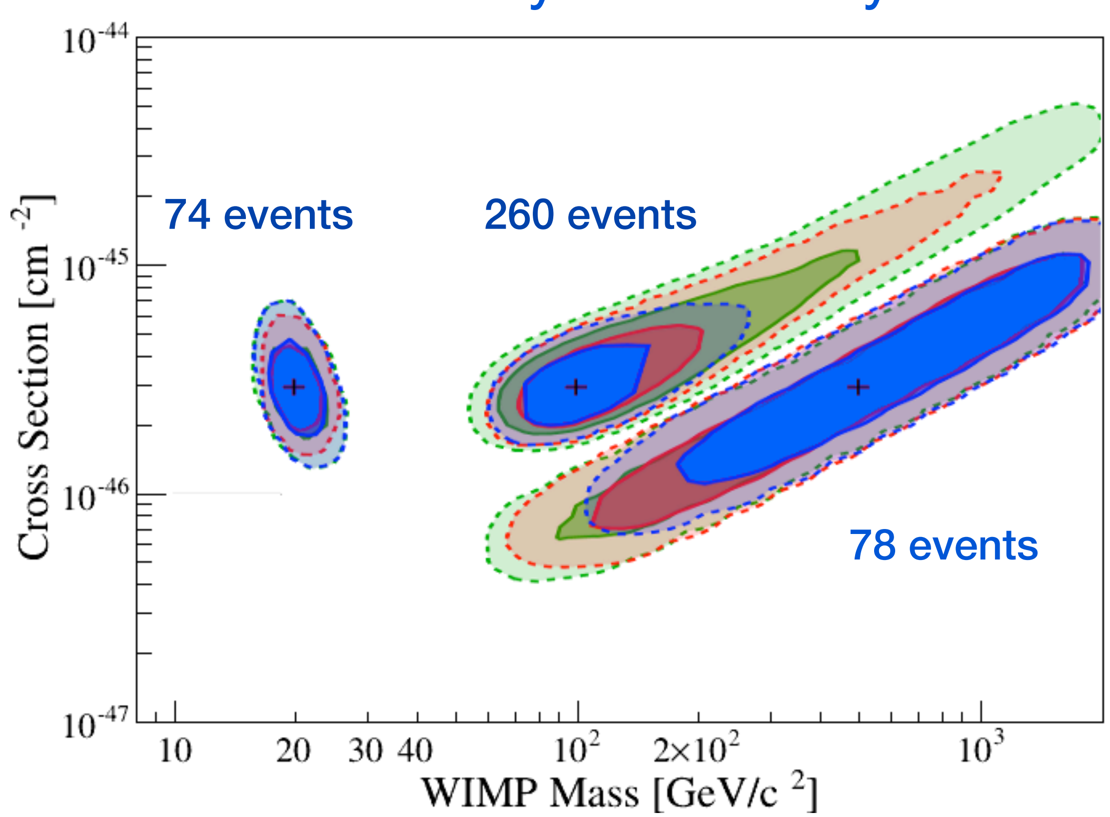
$$\nu + N \rightarrow \nu + N$$

JCAP01 (2014) 044

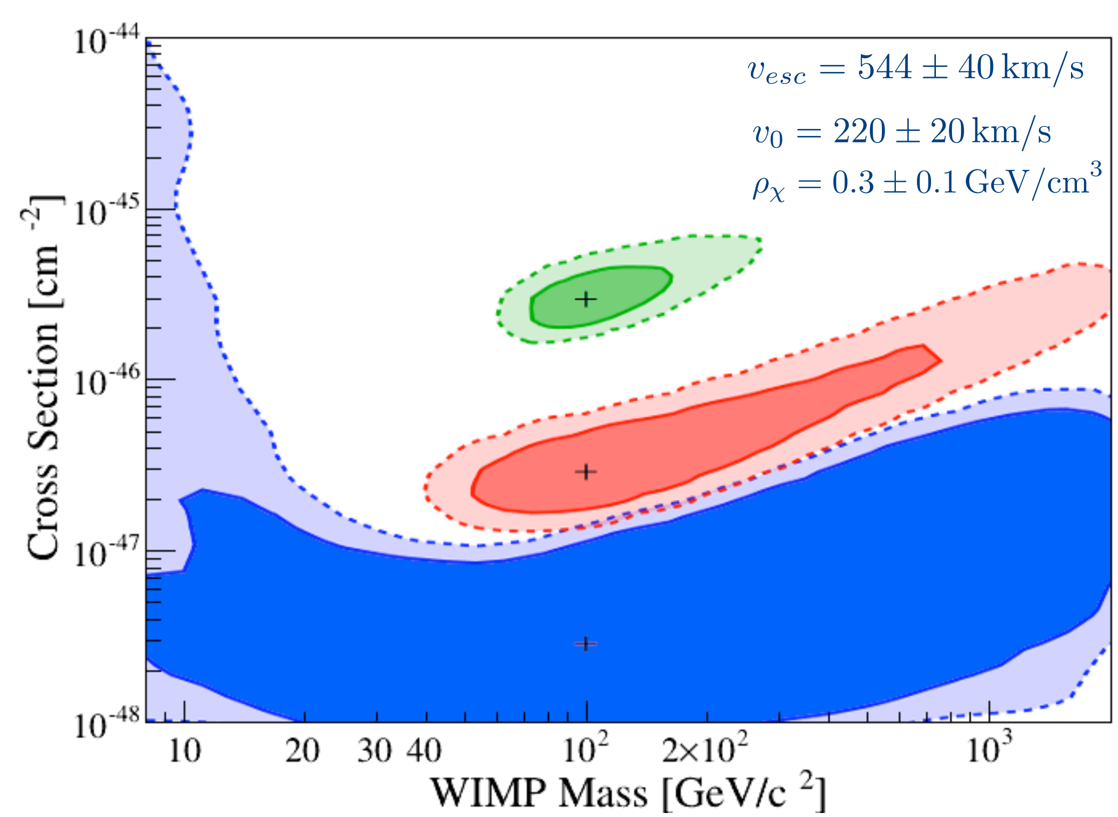
Physics reach: WIMP reconstruction

- Capability to reconstruct the WIMP mass and cross section for various masses and hypothetical cross sections (assuming different exposures)
- WIMP search regions: 6.6 - 43 keV_{nr} Xe, 20 - 150 keV_{nr} Ar

Xe 10 t yr, Xe 20 t yr
Xe 10 t yr + Ar 20 t yr



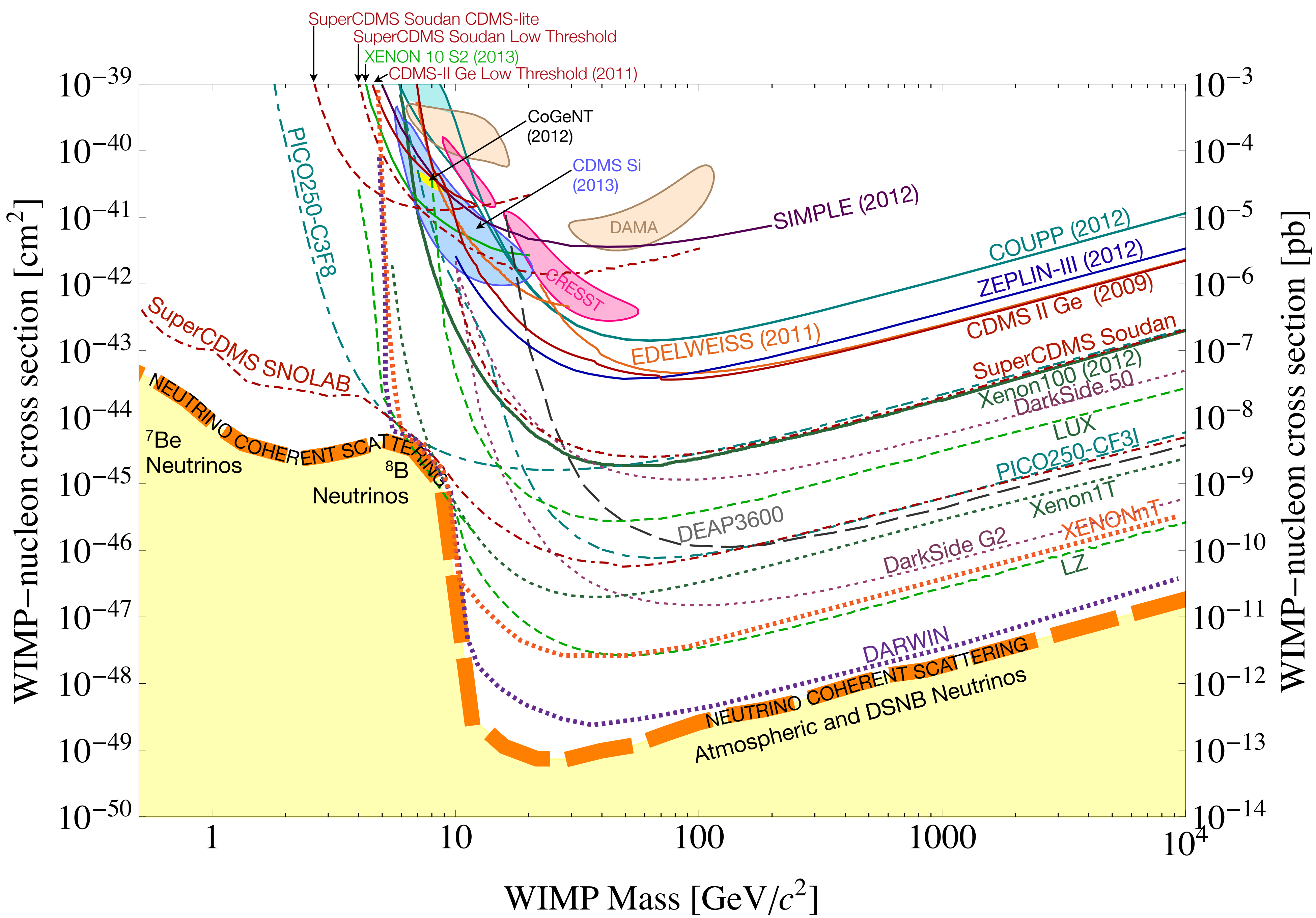
Xe 10 t yr + Ar 20 t yr for XS of:
$3x10^{-46}$ cm^2, $3x10^{-47}$ cm^2, $3x10^{-48}$ cm^2



Newstead et al., PHYSICAL REVIEW D 88, 076011 (2013)

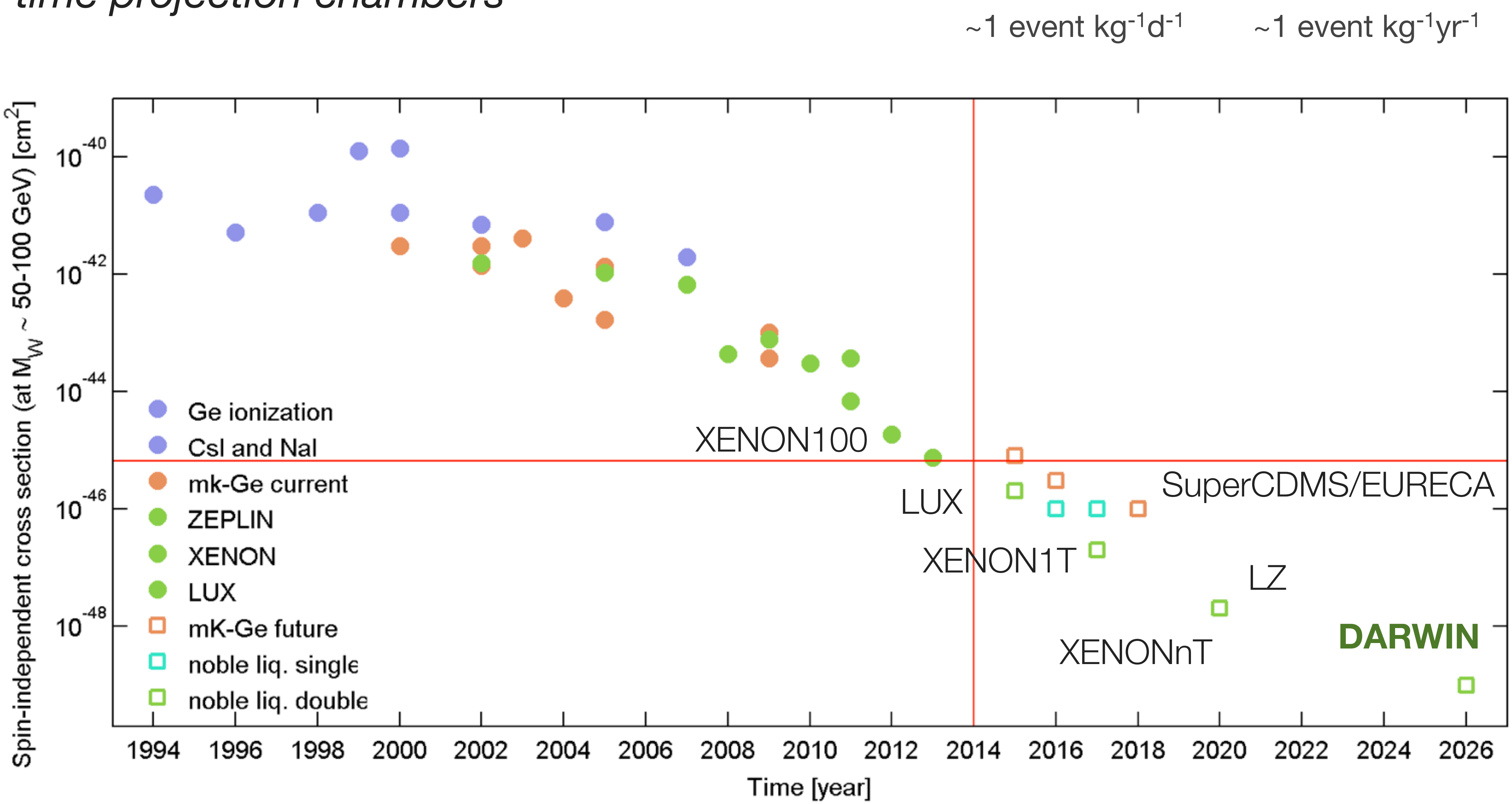
Physics reach: WIMP space

DARWIN can probe the experimentally available parameter space for WIMPs (m > 10 GeV/c²)



Evolution of the experimentally probed WIMP-nucleon cross section

- Sensitivity at WIMP masses above ~ 6 GeV/c^2 is clearly dominated by *noble liquid (Xe) time projection chambers*



Update from Physics of the Dark Universe 1, 94 (2012)

The DARWIN Consortium

29 groups from 9 countries

Summary

- XENON100 has reached its design sensitivity for medium-heavy WIMPs, and it can also probe other type of interactions (axions, ALPs, light WIMPs)
- XENON1T is well under constructing at LNGS & various home institutions, integration of all sub-systems is planned for spring 2015, with commissioning ~ mid 2015
- XENONnT is proposed as a fast upgrade to XENON1T, with a factor of 10 increase in sensitivity
- DARWIN - an R&D and design study for a third-generation, ‘ultimate’ WIMP dark matter detector - would operate 20t LXe/30t LAr detectors, with the goal of probing the entire experimentally accessible parameter space for masses >~ 10 GeV
- It could also detect pp-neutrinos in real time, with high stats, possibly coherent neutrinos scattering, axions, ALPs, etc

The end

Signal and backgrounds in DARWIN

Physics channel	Low-energy ν measurement	Dark matter search
Energy range	2–30 keV	2–10 keV
Assumptions	No ER/NR discrimination	99.5% ER rejection 50% NR acceptance
Rate	Events/(14 t·y)	Events/(14 t·y)
Solar pp neutrinos	1180	1.75
Solar ^{7}Be neutrinos	151	0.25
100 GeV/c^2 WIMP, 2×10^{-47}cm^2	42	19
40 GeV/c^2 WIMP, 2×10^{-48}cm^2	5.2	2.5
Coherent ν scattering	0.98	0.45
Detector components	19	0.03
^{85}Kr in LXe (0.1 ppt of $^{\rm nat}$Kr)	565	0.82
^{222}Rn in LXe (0.1 μBq/kg)	139	0.20
^{136}Xe ($2\nu\beta\beta$)	785	0.41

Table 2. Total solar neutrino and WIMP signal rates in DARWIN for a fiducial mass of 14 t of LXe and two WIMP masses and cross sections. The energy regions 2-30 keV and 2-10 keV are considered for the solar neutrino and the dark matter search, respectively. For the latter, a 99.5% rejection of electronic recoils, and a 50% acceptance of nuclear recoils is assumed.

JCAP01(2014)044

DARWIN: sensitivity to double beta decay of ^{136}Xe

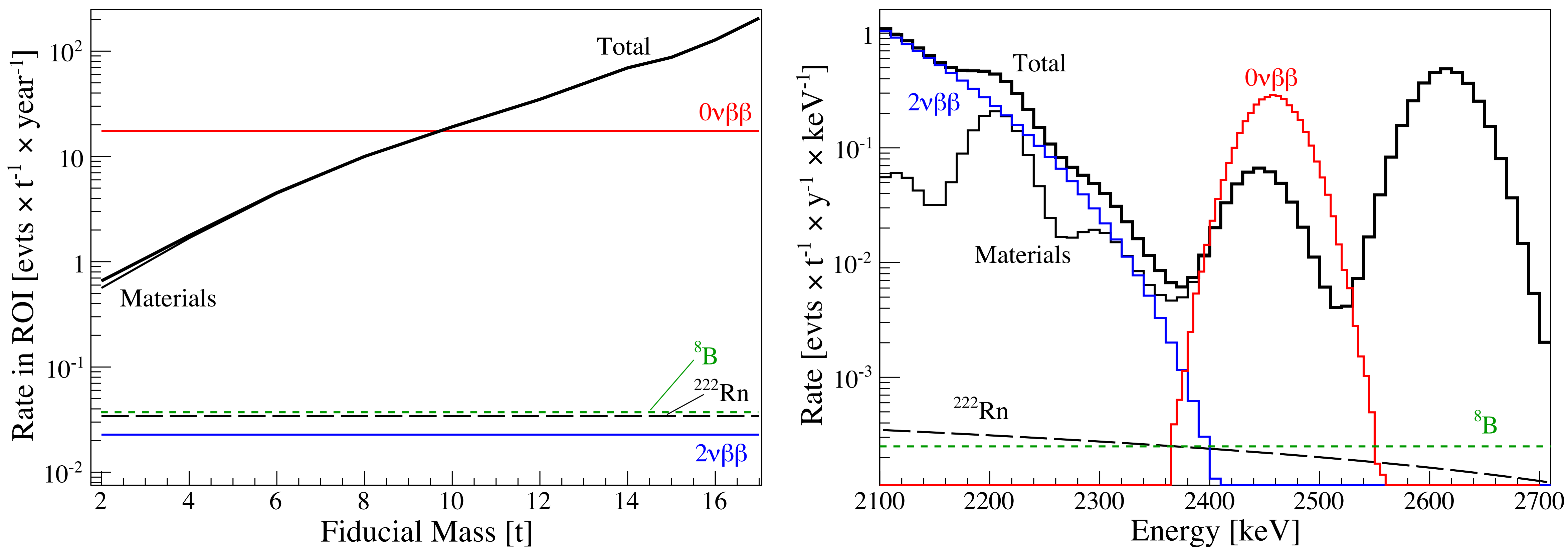


Figure 4. (Left): integral background rate in $\pm 3\sigma$ energy region around the Q-value (2385–2533 keV) as a function of fiducial LXe mass. (Right): predicted background spectrum around neutrinoless double beta decay peak for 6 t fiducial mass. We show the overall background (thick black solid) which includes contributions from detector materials (black), from 0.1 μBq/kg of ^{222}Rn in the LXe (black dashed), from ^{8}B neutrino scatters (green dotted)and $2\nu\beta\beta$-decays with $T_{1/2}$=2.11×10^{21} y inside the liquid xenon (blue). The potential signal for the neutrinoless double beta decay ($0\nu\beta\beta$, red) assumes $T_{1/2}$=1.6×10^{25} y.

JCAP01(2014)044

Signal and backgrounds in the bb-region

Energy range	Events/(6 t·y) 2385–2533 keV
Signal events	106
Detector components	27
^{222}Rn in LXe (0.1μBq/kg)	0.21
^{8}B (ν-e scattering)	0.22
^{136}Xe ($2\nu\beta\beta$)	0.14

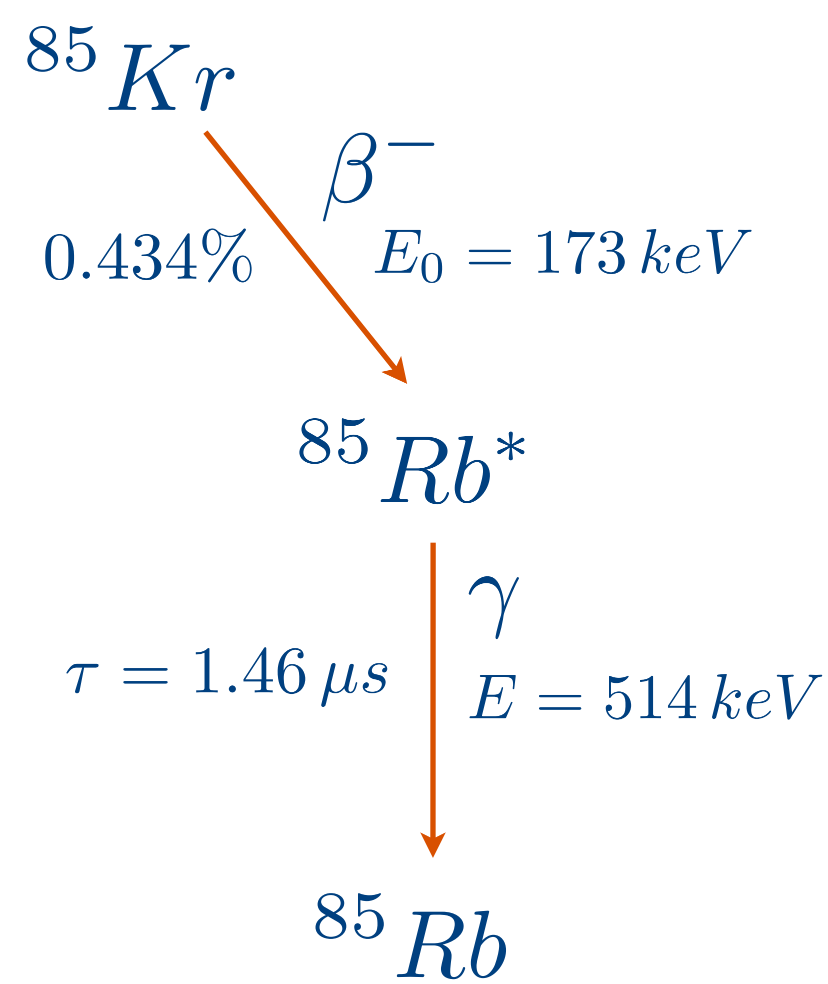
Table 3. Expected signal for the neutrinoless double beta decay (for $T_{1/2} = 1.6\times10^{25}$ y) and background events from detector components, ^{222}Rn in liquid xenon, ^{8}B neutrino scatters and from $2\nu\beta\beta$ decays of ^{136}Xe in the energy region 2385–2533 keV. A fiducial mass of 6 t of LXe and an energy resolution of $\sigma/E = 1\%$ at the Q-value is assumed.

JCAP01(2014)044

Using a fiducial mass of 6 t of xenon and an exposure of 30 t yr, a sensitivity to the neutrinoless double beta decay of 136Xe of $T_{1/2} > 5.6 \times 10^{26}$ yr can be reached

Backgrounds

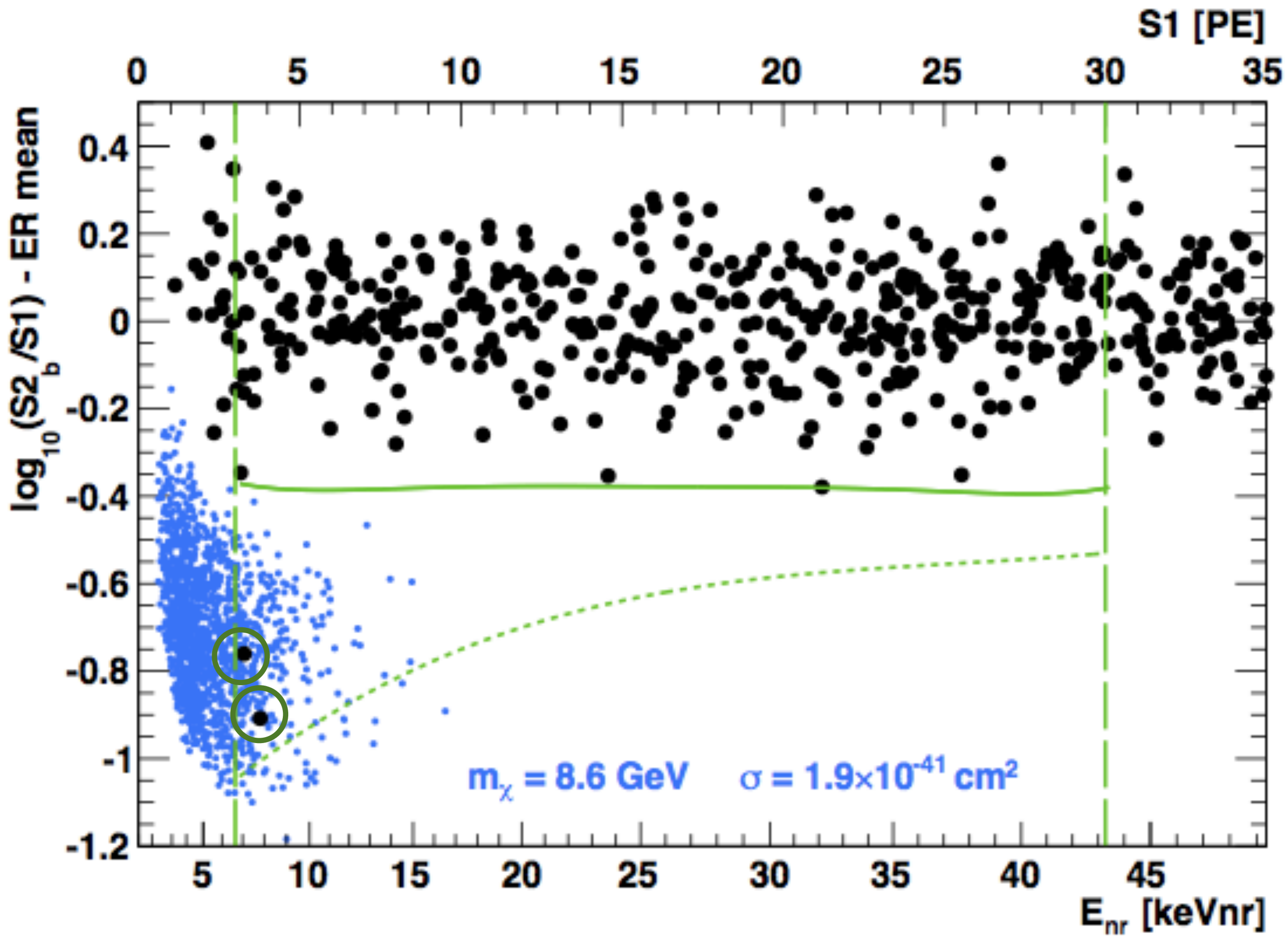
- XENON100: materials, radon, krypton
  - current run: < 1.3 ppt (90% C.L.) ^{nat}Kr=> < 0.05 mdru from ^{85}Kr (^{85}Kr present at 10-11 mol/mol in ^{nat}Kr); 65 μBq ^{222}Rn
- XENON1T: radon, krypton, materials, solar neutrinos
  - assumptions 0.5 ppt ^{nat}Kr; 1 μBq/kg ^{222}Rn
- DARWIN: solar neutrinos, double beta decay (^{136}Xe), ^{85}Kr, ^{222}Rn, detector components
  - assumptions 0.1 ppt ^{nat}Kr; 0.1 μBq/kg ^{222}Rn
- NR background: sub-dominant

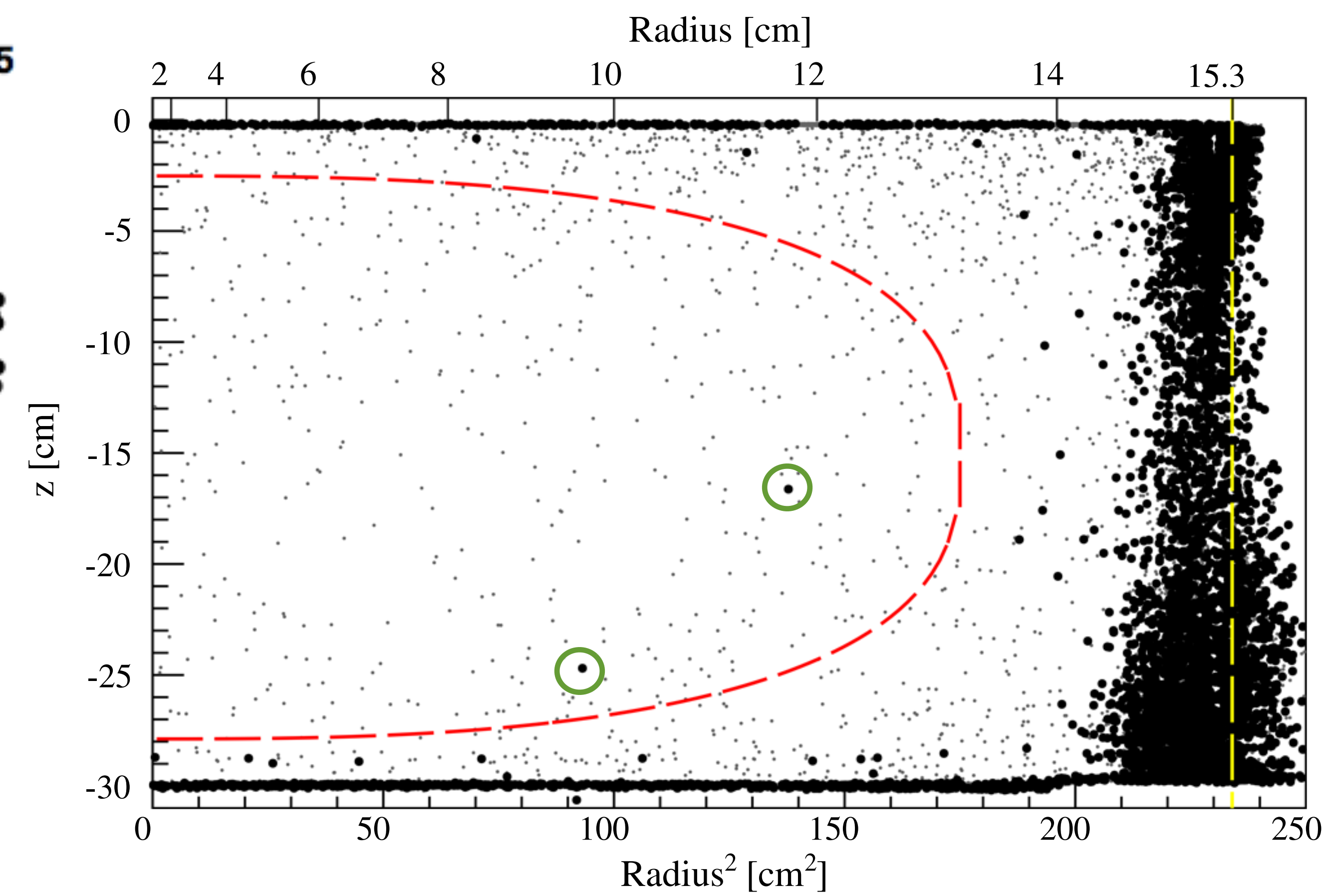


XENON100: signals, and background reduction

- Fiducial volume and ER/NR discrimination cut

XENON100: WIMP with m_W = 8.6 GeV





WIMP-nucleon cross section : 1.9 x 10^{-41} cm^2;
CDMS Si results, 140 kg d

observed: 224.6 live days, 34 kg,
1 background event expected